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THESIS

USING AGENT-BASED DISTILLATIONS TO EXPLORE LOGISTICS SUPPORT TO URBAN, HUMANITARIAN ASSISTANCE/DISASTER RELIEF OPERATIONS

by

Eric Wolf

September 2003

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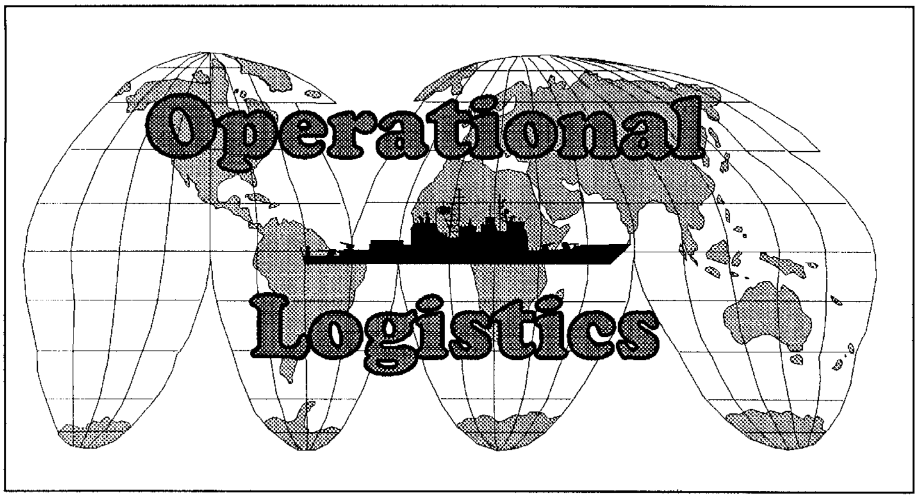
Second Reader:	Lloyd Brown

Amateurs discuss strategy,
Professionals study logistics!



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13. ABSTRACT (maximum 200 words)

There are two motivations for studying Humanitarian Assistance/Disaster Relief (HA/DR) operations. First, the Marine Corps will be a first-responder in the future. Second, logistics support takes on a primary role. This thesis identifies the potential for using agent-based models to support logistical decision-making in an urban, HA/DR environment. We develop a simulation using Map Aware Non-uniform Automata (MANA). Our scenario depicts a relief convoy with security attachment, operating on urban terrain. The convoy moves to an HA/DR site where they distribute food to neutrals (locals) who have made their way to that site.

We couple data farming with a Latin Hypercube design of experiment to explore very large data space. Forty variables are identified. We establish 640 different design settings and each setting is replicated 50 times producing a 32,000-point dataset. We use regression to fit several models. The conclusions from this thesis suggest: coupling intelligent designs with data farming is effective at exploring large data space; mission success in HA/DR operations may depend on only a handful of factors; understanding local communications is the key to mission success; success cannot be determined based solely on the factors the convoy controls.

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USING AGENT-BASED DISTILLATIONS TO EXPLORE LOGISTICS SUPPORT TO URBAN, HUMANITARIAN ASSISTANCE/DISASTER RELIEF OPERATIONS

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THESIS DISCLAIMER

The reader is cautioned the computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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I begin by thanking God for creating me exactly the way He wanted me. He gave me skills, inspirations, dreams, and passions and put me in a place where I would grow mentally and spiritually while having the privilege of serving others. The bible says more clearly than I can, “it is in Him we live, and move, and have our being.” Acts 17:28

I also recognize my great thesis team! Niki, your initial enthusiasm for this research was the spark I needed to set off down this road, and that enthusiasm never dipped. Maj Brown, you are the embodiment of the Marine analyst. When I wondered why I was doing this, I pictured myself filling your shoes. And Susan, your patience and encouragement finally convinced me that maybe I really can do this stuff.

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always cherish. You have been “salt and light” to me and to the world around you. To Zack and A.J., I have only two words; duct tape. Thank you for keeping me straight on what’s important in my life. Finally, Juliet. For 18 years you’ve followed me around and been excited about our lives together. Most importantly, I know I’m loved.

God bless you all!

EXECUTIVE SUMMARY

There are two main motivations that have driven the author to actively study Humanitarian Assistance/Disaster Relief (HA/DR) operations. The first is the compelling fact that the Marine Corps will be called on as a first-responder to humanitarian crises in the future. The second is that, in HA/DR operations, logistics support takes on a primary role. Because the Marine Corps operates in a forward-deployed status, it is uniquely positioned and equipped to rapidly respond to pleas for help. Afloat units deploy with a full compliment of equipment, allowing them to provide immediate life-saving services and then, if necessary, transition to relief and sustainment operations. Furthermore, in HA/DR operations services such as transportation, distribution, medical attention, and engineering efforts often rise to the top of the priority list. Logisticians must be prepared to take the lead in planning for HA/DR operations.

This thesis identifies the potential for using agent-based models to support logistical decision-making in an urban, HA/DR environment. We have developed a simulation using the modeling environment Map Aware Non-uniform Automata (MANA) which allows us to inculcate agents and squads with personality and physical characteristics. Our scenario depicts a relief convoy, augmented with a security attachment, operating on urban terrain. The convoy follows a given route to an HA site where they distribute food to neutrals (locals) who have made their way to that site.

From the beginning, we were interested in exploring the complexities of HA/DR operations with the foreknowledge that our model would best serve as a screening tool. To explore the potentially huge data space we coupled the technique of data farming our simulation over a cluster of supercomputers with a Latin Hypercube experimental design. We identified 40 squad/state/factor combinations and established 640 different design settings for those combinations. Each setting was replicated 50 times producing a 32,000-point dataset.

Finally, we fit our dataset and drew conclusions relevant to our scenario. We used JMP Statistical Discovery Software™ and the additive multiple linear regression technique to fit our dataset. Every term included in the final model was then justified and we interpreted the operational implications of our model. We next suggested two additional models by subsetting our data. The ramifications of these experiments are also detailed.

The results of this thesis work suggest the following:

- Logisticians must study HA/DR operations, paying attention to lessons learned and planning considerations.
- There is great utility in using agent-based models as a means of exploring highly complex scenarios.
- Logistics functionality and measures of effectiveness must be added to agent-based models in order to fully exploit their benefits.
- Coupling intelligent designs with the speed of data farming has a multiplying effect on the number of factors that can be explored.

- Even though HA/DR operations are replete with variables, mission success may be dependent on only a handful of these factors.
- Interactions between the few, highly important variables account for much of mission success.
- When conducting logistics operations in an HA/DR environment, understanding and tapping into local communications is the key to mission success.
- Marines should not predict the success of a mission solely on the variables they have control over.

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I. INTRODUCTION

> *It is in the cities of the future that most disaster victims will be found. People trapped in poverty, living on marginal land exposed to industrial hazards and indifferent city governments, will make up the majority of disaster victims in the near future.*

Charles Page

International Federation of the Red Cross, 1997

A. MOTIVATION

There are two main motivations that have driven the author to actively study Humanitarian Assistance/Disaster Relief (HA/DR) operations. Foremost is the compelling fact that the Marine Corps can expect to be importuned as a first-responder to humanitarian crises in the future. The second impetus is that in HA/DR actions the primary role, and in fact accountability for success, is often apportioned to the combat service support community.

The Marine Corps and its Navy partner routinely operate in forward-deployed regions, uniquely positioning them to rapidly respond to pleas for help. These cries may be for immediate relief from the crippling effect of a natural disaster, as was the case when an earthquake recently struck the country of Turkey. They may be the swelling voices of citizens trapped in a man-made disaster brought on by civil conflict such as was the case most recently in Liberia. In either circumstance, the Marine Corps and the Navy are trained and outfitted to respond purposefully. The Marine Expeditionary Unit (MEU) deploys with a full compliment of equipment allowing it to provide

immediate life-saving services and then transition to relief and sustainment operations.

Again, in an HA/DR environment services such as transportation, distribution, medical attention, and engineering efforts often rise to the top of the priority list. Logisticians may find themselves in the unique position of being the main effort with infantry providing security for their missions. Furthermore, logisticians must be prepared to take the lead in drafting operational plans.

B. PURPOSE

The purpose of this thesis is to identify the potential for using agent-based models (ABMs) to support logistical decision-making and mission success in an urban, HA/DR environment. We have developed a simulation, which will allow us to inculcate squads with general characteristics, as well as personality and physical characteristics. We will exploit these properties to answer general questions about convoy cohesiveness and movement speed when operating in an urban environment on a relief supply mission. We also consider how information must propagate between neutrals in order for a maximum number to be fed. Finally, we seek to identify ways agent-based models can be used to predict starting parameter values for more complex models.

C. SCOPE

There are an endless number of questions and issues regarding tactics, equipment, leadership, coordination, terrain effects, behavior of the neutral agents, and introduction of hostile agents (just to name a few) that could be explored. In order to keep this thesis within the

limits of what can be reasonably explored, the following has scoped the direction of the research:

- Summarize three HA/DR operations as case studies.
- Review the lessons learned from these previous operations.
- Develop an appropriate measure of effectiveness.
- Present an overview of the functions within the modeling environment we have chosen.
- Identify, from initial simulation runs, pertinent parameters and set factor ranges we intend to use in our full model.
- Recap the creation of our simulation model.
- Explain the design of the experiment.
- Review data farming and explain how the technique has been applied to our design.
- Fit various models to our full dataset.
- Present the findings and make recommendations on how they may support logistics operations in humanitarian crises.
- Consider how agent-based distillations (ABDs) may be used for finding beginning parameter values to current aggregate models.

D. INTRODUCING AGENT-BASED MODELS

Many areas of military concern, such as command and control of forces, operations on urban terrain, and HA/DR operations, are replete with human interactions. The complexity of these operations along with the confluence of possible interactions outside of the control of the local commander creates a situation that is not easily modeled. Increasingly these multifaceted operations are being studied using ABMs.

ABMs provide an environment in which entities, controlled by decision-making algorithms, can maneuver. These entities, known as agents, execute many local interactions resulting in the emergence of global behaviors. The agents often interact in a self-adaptive, non-linear manner with each time step. This self-adaptive behavior creates a vast number of variables, and facilitates research into emergent behaviors. The aggregate effects of the myriad of individual decisions can be studied, for a given scenario, in order to assess the effects on the whole system. These systems, including the agents, the environment in which they maneuver, and the rule-set by which they make decisions, are known as complex adaptive systems (CASs) [Stephen et al., 2002].

E. INTRODUCING PROJECT ALBERT (PA)

The validity and usefulness of ABMs remains an ongoing contention within the analysis community. The Marine Corps, through the proponency of Project Albert (PA), is one of the leading agencies working to address this area of research. Specifically, PA is interested in exploring ways of sorting through the huge sample spaces generated by an agent-based approach to gain insight into real-life, operational problems [Horne and Johnson, 2002]. To date, PA has ushered the development of several agent-based modeling environments. These environments have been used to generate abstract models of real-world problems. Because of the decidedly sparse, and thereby rapid, approach to modeling, the project calls the abstracts distillations, or *agent-based distillations* (ABDs) [Horne and Johnson, 2002].

Concurrently, PA has introduced the idea of *data farming*. Data farming is an iterative technique that resamples areas of the data space that the analyst wants to research more closely. This resampling can be conducted quickly because PA uses supercomputers to execute thousands of model runs in a relatively short amount of time [Wu, 2002]. Furthermore, the setup and feedback of the data farming runs can be done over the Internet through a simple interface. PA has put together a complete package, including a set of agent-based models, an easy-to-use data farming process, and visualization tools, which facilitates research into CASs.

F. INTRODUCING THE PROBLEM

Most operators, logisticians, and analysts think of logistics support in terms of hard numbers, such as the number of meals delivered or the number of miles driven. However, logistical scenarios are exactly the type of loosely-defined problems which lend themselves well to abstract study using agents. For example, one can think of any number of decisions that could affect the success of a simple resupply mission in an urban HA/DR environment. Intangibles, such as foot traffic, road accessibility, harassment, and the necessary interaction between the military and Non-Governmental Organizations (NGOs) and Private Voluntary Organizations (PVOs) can all have effects on the success of the operation. This thesis will apply data farming techniques to an ABD that models logistics support in a HA/DR environment in order to identify which input variables have the most effect on mission success.

G. INTRODUCING OUR SIMULATION

While our simulation model will be fully developed in a later chapter, a snapshot of the base-case scenario will be given here to facilitate the problem description and formulation. This screenshot is best viewed in color. Figure 1 depicts a screen capture of an execution of our ABM. We developed the simulation in the modeling environment Map Aware Non-uniform Automata (MANA, pronounced *marnar*). Blue agents in the screen shot represent a convoy of relief supplies, including a U.S. Marine Corps security element. The yellow entities are neutral agents, those requiring aid. We have included a lone red agent in our base-case scenario to introduce the possibility of random harassing fire as might be encountered in a man-made humanitarian crisis such as a civil war.

Figure 1. MANA food distribution base-case depiction.

H. THESIS ORGANIZATION

Chapter II begins by covering the background relative to why this thesis is both timely and important to future conflicts and crises. We then justify the aspects of HA/DR operations we have tried to include in our model. Next we discuss, in general terms, appropriate Measures of Effectiveness (MOEs) for HA/DR operations and how we arrived at the specific MOE used in our analysis.

In the third chapter, the internal workings of MANA and the principles of data farming are discussed more thoroughly. The setup of our scenario is delineated, including what each parameter value is meant to represent and how those values were chosen. The results of initial runs are explained as a means of introducing the model used in the final analysis.

Chapter IV describes the analysis methodology used to fit and interpret the final MANA model. We also discuss the output from our model and the various statistical tools used for analysis.

The simulation results and models we fitted, along with a thorough discussion, are presented in Chapter V. Finally, conclusions and recommendations for future research are suggested in Chapter VI.

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II. BACKGROUND AND MOTIVATION

> *…an international coalition analogous to Desert Storm, built around a core of two U.S. divisions and led by the First Marine Expeditionary Force… Only this sort of large-scale, rapid-action force could blanket and extinguish the conflict so that relief supplies could reach the hundreds of thousands of people at risk before it was too late.*

Ambassador Robert Oakley
Special Envoy for Somalia, 1997

A. CHAPTER OVERVIEW

This chapter opens by defining many of the expressions included in the body of verbage common to the HA/DR community, as well as *lingua franca* used by those operating within the PA arena. Next we present three significant HA/DR actions as a means of conveying the core of what is typically required of responding agencies. From these operations we glean a number of lessons learned that we have then tried to incorporate into our model. We discuss the problems inherent with selecting a measure of effectiveness in an HA/DR operation and then justify the choice we have made. As a final point, this section explicates the motivation behind why we were interested in researching this problem.

B. DEFINITIONS

The breadth and scope of HA/DR operations, along with the plethora of responding agencies, contribute to an on-going problem within the community of imprecise definitions. Whenever possible we will use definitions taken from Department of Defense sources. If a definition

comes from another source, that will be noted. We also define many of the terms common to the PA environment.

- Agent Based Distillation (ABD) – the term used to reflect the difference between MANA and more detailed models that also use agents. The term reflects the intention to model just the essence of a problem [Anderson et al., 2003].
- Agent Based Model (ABM) – a model that contains entities that are controlled by decision-making algorithms [Anderson et al., 2003].
- Complex Adaptive Systems (CAS) – agent-based models consisting of entities, controlled by decision-making algorithms, reacting individually but creating an emergent global response [Anderson et al., 2003].
- Data Farming – the application of agent-based models, computing power, and data visualization to help answer complex questions [Wu, 2002].
- (Foreign) Disaster Relief (DR) – Prompt aid which can be used to alleviate the suffering of (foreign) disaster victims [MCWL, 1999].
- Humanitarian Assistance (HA) – Programs conducted to relieve or reduce the results of natural or manmade disasters or other endemic conditions such as human pain, disease, hunger, or privation that might present a serious threat to life or that can result in great damage to or loss of property [MCWL, 1999].
- Non-Governmental Organizations (NGO) – Transnational organizations of private citizens that maintain a consultative status with the Economic and Social Council of the United Nations [MCWL, 1999].
- Private Voluntary Organizations (PVO) – Private, non-profit humanitarian assistance organizations involved in development and relief activities. PVOs are normally U.S. based [MCWL, 1999].

C. BACKGROUND

Much of the data given as background in this section has been culled from many sources and often varies from source to source. The data usually was not originally gathered for the specific purpose of compiling statistics and should therefore be regarded as indicative rather than exact. These statistics are offered in order to gauge the relative changes that have taken place.

With the fall of the Iron Curtain the geo-political landscape changed significantly. The international balance of power, that had been consolidated in the hands of the two nuclear superpowers (the U.S.S.R. and the U.S.), began to be diffused to nations with regional strength. The relative strength of the world’s remaining superpower (the U.S.) has declined even though its absolute strength remains unchallenged. The U.S. found itself thrust into the position of being the only nation capable of responding, worldwide, to crisis or conflict.

It was thought that the end of the Cold War would usher in a time of world peace and, undoubtedly, the prospect of global nuclear war is no longer with us. However, during the Cold War there was a sense the superpowers would keep their proxy nations in check, thereby suppressing regional aggression. Since then the reality is conflict has increased rather than diminished, especially small-scale or Low Intensity Conflict (LIC). International trade has clashed with national fractions, ancient ethnic rivalries, and religious divisions, to set the stage for constant political and social unrest.

Between 1948 and 1978 the United Nations Security Council approved only 13 peace operations and none at all from 1979 to 1987; thus approving a total of only thirteen in almost 40 years. From 1988 through December 1999, 38 peace operations were established [CBO Paper, 1999]. This trend is expected to continue. The Global Humanitarian Emergencies Projection [NIC, 2001] suggests that, although the number of acute world emergencies is down from 25 in January of 2000, there are presently 20 humanitarian crises ongoing in the world. In addition, this report cites internal war as a main cause for the proliferation and prolongation of these humanitarian crises. The upswing in civil unrest within nations is generally thought to be related to the breakdown of the *de facto* bi-polar superpower arrangement.

It should also be noted that these 20 emergencies encompass only the most acute problems. The World Disasters Report, published yearly by the Red Cross, counted 39 countries in 1998 where people were in need of some sort of assistance [IFRC, 1998]. Appendix A provides specific details on the number of people affected and the types of emergencies they are facing. Also in Appendix A is a table showing the 39 countries that were most at risk and what types of privations they faced.

The emergence of the United States as the world’s only superpower has thrust America into the position of global mediator and provider in times of crisis. As this nation’s “911” force, the Marine Corps has often been the initial force responding to cries for help, whether these pleas are the result of internal chaos or natural disasters. Over

the past dozen years the Marine Corps has participated in numerous HA/DR operations. In May 1991, Marines returning from Operation Desert Storm were diverted to provide immediate assistance to the country of Bangladesh following a cyclone that killed more than 139,000 people and left 2.7 million homeless [Trader et al., 1998]! At the same time, Operation Provide Comfort brought relief supplies to more than one million refugees in the mountains of northern Iraq [Trader et al., 1998]. Sub-freezing temperatures, disease, malnutrition, and dehydration were mitigated through the efforts of Marines and others. Marines participated in Operation Restore Hope in December of 1992, providing hunger relief to the country of Somalia at a time when 3000 Somalis per day were dying and another 1.5 million were at risk of starvation [U.S. Army War College, 1997]. Recently Marines responded with aid to the people of East Timor and Afghanistan. Currently there are Marines providing limited support to a multi-national peacekeeping force in the country of Liberia.

If we have not yet provided convincing evidence of the importance and current application of this research, consider the words of Secretary of State Colin Powell when he spoke on August 11th 2003 regarding the situation in Liberia. The secretary cited a “desperate need for food to be delivered” and said Marines could help secure the port and bring humanitarian supplies ashore [Vick, 2003]. The Marine Corps can expect to be further involved in these types of operations in the near and continuing future.

D. THREE HA/DR CASE-STUDIES

By taking a brief look at past HA/DR operations we can learn general lessons that may be incorporated into our

model. We have chosen these three operations for several reasons. First, in each case, Marines were directly involved immediately upon onset of the crisis. We believe future crises will see the introduction of Marines at onset for two reasons: Marines are forward-deployed and thus readily available, and the Marine Corps is equipped with helicopters, trucks, generators, amphibious craft, water purifying equipment, and much more which enable it to immediately save lives and offer assistance. Another reason for studying this set of operations is their tasks parallel the type of operations we wanted to model. Finally, the three operations cover the spectrum of the level of violence involved in HA/DR operations and cover the degree of involvement Marines had in rendering humanitarian assistance. Although there are several studies containing summaries of past HA/DR operations, we have relied on Trader et al., 1998 for this summary.

1. Operation Provide Comfort

In late February and early March of 1991, Iraqi Kurds, emboldened by the defeat of the Iraqi army, and with the encouragement of the U.S. government, rebelled against the Iraqi government. The uprising was quickly and brutally suppressed, causing over one million Kurds to flee into the mountains of Turkey and Iran. The refugees suddenly found themselves without shelter and in need of water, food, and medicine. This need, coupled with sub-freezing temperatures, led to rampant exposure, dehydration, hunger, and disease, as well as outbreaks of cholera, dysentery, measles, and typhus. The President authorized an immediate airlift of supplies, and a plan was drawn up to establish a

safe haven within Iraq and encourage the repatriation of the Kurds.

At this point it is essential to introduce the idea that every HA/DR operation will include tasks that are political in nature. As egalitarian as we Americans like to believe we are, the United States government has an opportunity and agenda that dovetail with any immediate crisis. That is to say, while we may be feeding people or delivering life-saving medicine, there is a greater, long-term political goal the United States hopes to further. This point should not be considered callous or seen as negative. It is simply a function of trying to treat the cause of a crisis as well as its symptoms. For example, in providing relief to the Kurds, we also hoped to nurture a relationship with them that would one day be used as a base of support in the ouster of Saddam Hussein from Iraq.

The Operation Order for Operation Provide Comfort included the following tasks:

- Coordinate drop zones and food distribution.
- Conduct census, organize camps and food and water distribution, improve sanitation, and provide medical care.
- Identify site locations for temporary shelter out of the mountains.
- Erect temporary living facilities.
- Relocate Iraqi Kurd displaced civilians to supportable locations.
- Establish way stations along the routes between refugee camps and Zakho.
- Prepare Zakho for refugees.
- Facilitate transfer of Kurds back to their homes.

- Integrate civilian agencies into process of getting Kurds out of the mountains and into transition refugee camps, and eventually returning them to their homes.
- Transfer administrative and support functions to civilian organizations.

Before beginning our analysis of this operation we will introduce the other two operations and then summarize the lessons learned from all three at once.

2. Operation Sea Angel

In May 1991, a cyclone hit Bangladesh killing more than 139,000 people and leaving approximately 2.7 million homeless. The storm also caused extensive damage to the country's infrastructure, particularly roads and communications networks. Seaports and airports were inoperable, making it very difficult for assessment teams and relief agencies to enter the country. When relief supplies were introduced into the country, the extent of damage to the lines of communication (LOC) made distribution nearly impossible overland. Helicopters, landing craft, and amphibious vehicles were needed.

The President authorized U.S. forces to conduct relief missions. Because it was important to facilitate the perception that the newly-formed democratic Bengalese government was in control of the relief effort, Marines conducted most of their operations from off-shore. The After Action Report described the following set of tasks:

- Conduct surface and helicopter support missions for disaster relief operations.
- Coordinate operations.
- Provide communications capabilities and support to assessment teams and NGOs.

- Provide transport of relief supplies.
- Conduct reconnaissance of rivers, landing zones, beaches, cushion landing zones, and landing sites.
- Conduct assessments of areas requiring immediate assistance.
- Load/unload supplies at airports.
- Conduct damage, engineering, and medical assessments.
- Establish sites, where directed, to provide water.
- Conduct daily coordination meetings with government of Bangladesh to coordinate relief efforts.
- Coordinate with other international partners assisting the relief effort.

3. Operation Restore Hope

Following the overthrow of the President of Somalia in 1991, the country deteriorated into anarchy as tribal factions vied for control. Incident to the fall of the government, several humanitarian organizations had been providing foodstuffs. These organizations immediately became the target of banditry and lawlessness, causing the onset of a famine that eventually swept over the entire country. The United Nations initially sent 500 troops to provide security for NGO/PVO relief workers. By the summer of 1992 it was clear a stronger force was needed and a large-scale relief effort was in order. The Office of Foreign Disaster Assessment, an arm of the State Department, had estimated “one quarter of the population at risk of starvation, one-fourth of all children under the age of five already dead and 800,000 Somalis displaced or refugees” [9]. The President announced Operation Provide

Relief to provide an emergency food airlift. The military mission had four objectives:

- Secure major air and seaports, key installations, and food distribution points.
- Provide open and free passage of relief supplies.
- Provide security for convoys and relief organization operations.
- Assist UN/NGOs in providing humanitarian relief operations under UN auspices.

E. LESSONS LEARNED

A large body of lessons learned has emerged from these and other humanitarian operations. The list we present is certainly not all-inclusive but contains the major aspects that should be kept in mind when planning HA/DR operations.

- Plan the political, military, and humanitarian campaign as a unified, whole effort.
- Initiate action as soon as possible. The most dramatic return on investment of manpower, equipment, and relief supplies is realized in the initial stages of the operation.
- Set measurable and realistic tactical and operational objectives with the end-state and timeline in mind.
- Continually reassess the political, military, security, and humanitarian situation with respect to those objectives.
- As much as possible, foster and maintain unity of command and cohesion of effort among the various NGOs/PVOs, military, international, and host-nation agencies.
- Wage a multifaceted information campaign aimed at the local population and broaden public opinion.
- Do not settle for partial solutions that leave room for problems further down the road.

- Plan for a gradual turnover of the effort, from military and relief groups, to civilian and international development agencies.

F. LEARNING FROM THE PAST

In the operations summarized and the lessons learned, there are a number of common ideas. We believe these ideas will be common to future HA/DR operations and try to incorporate them into our research model. We now describe those elements.

1. Convoy Operations

Each of the abovementioned operations involved the transportation and/or distribution of relief supplies. There are a number of ways to measure the effectiveness of such tasks. This is an aspect of HA/DR scenarios that we can both model and measure, so the core of our scenario is built around a relief convoy enhanced with a Marine security detachment.

2. Humanitarian Assistance Sites

In each of the case studies a secure HA site needed to be established, and, in the case of the non-permissive environments, security of the relief effort itself was undertaken. We have included two secure humanitarian sites in our simulation.

3. Civil/Military Cooperation

Throughout the lessons learned, and in each of the operations presented, there was a call for deeper military/civilian coordination. In our model, Marines provide direct support to a supply convoy. While we do not explicitly formulate agents or networks to model military/civilian interaction, we believe our depiction is general enough to consider the convoy as either an NGO/PVO or as a Marine Corps asset.

4. Urban Environments

There are two urban scenarios that this thesis attempts to address. The first reflects the case where affected people stay home but still require humanitarian aid. The second considers the situation where people are displaced and stay in a host community [IFRC, 1998].

In the first scenario, the affected population remains in their homes. This is usually the case when there has been a natural disaster such as a hurricane, flood, or earthquake that does not necessarily destroy homes, although they may be damaged, but does cut off or infringe on local services. This situation may also arise, as in our simulation, when there is short-term famine. Whenever residents have the option to stay in their own homes they will choose to do so, because they are familiar with the surroundings, can prevent looting, and can move within the familiarity and security of their local community. In the long run this is a much more sustainable solution which facilitates a quicker return to normalcy than responses which require residents to relocate. In such cases there is potential for the emergency to be short-lived.

The second scenario involves people who are displaced, by either a natural or man-made disaster, and stay in host communities. For example, extensive flooding or regional civil strife may drive people from their homes. They will often migrate to the next closest population center or the location of their closest relatives. When this happens, governments and agencies will need to provide relief to the entire population since both residents and displaced people are affected. Our model easily embodies this scenario if

we consider the HA sites as community feeding centers, similar to our “soup kitchens.”

G. DETERMINING A MEASURE OF EFFECTIVENESS (MOE)

1. What is an MOE?

An MOE is an objective, quantitative expression of performance appropriate to the context in which it is being used. Generally an MOE relates resources input to obtain a given measure of output. An MOE must have real scales upon which to measure inputs and outputs. Schrady says, “MOEs in the affairs of man and society tend to be relative rather than absolute” [Schrady, 1989]. Identifying appropriate MOEs in HA/DR operations will always be controversial because of the political nature of the operations themselves. A Center for Naval Analysis report [CNA, 1996] identifies five types of measures.

The five measures they offer are applicable only within a given level of warfare -- tactical, operational, or strategic. Following are the five measures and what they are intended to reveal:

- *Level-of-Effort measures* describe the magnitude of specific force actions. Examples include tons or food delivered or number of convoys escorted. As such, these measures are not MOEs but give support to MOEs.
- *Task-performance MOEs* encompass many of the actions described by individual level-of-effort measures, placing these actions into a larger context. These measures compare the action undertaken to address a specific situation with the total requirement.
- *Mission-level MOEs* are broader still, providing insight into progress toward the larger political objectives.

- *Transition measures* provide insight into progress toward the transition of responsibilities to another force or organization.
- *General indicators* provide insight into progress on improving the situation. These are a non-quantitative tool –- a supplement to MOEs –- that can indicate progress. An example would be crowds returning to marketplaces.

So, from the list above, we see we can measure effort at the task level or the mission level. Level-of-effort measures will support our task-performance measures. Transition measures are beyond the scope of what we intend to cover; nor we will we consider general indicators. Furthermore, it will help to limit our discussion to the tactical level. At the operational level or above we quickly get tied to political objectives that are neither easily defined nor readily measurable.

2. Common Problems in Choosing an MOE

In October of 1998 Hurricane Mitch veered toward the countries of Belize, Honduras, El Salvador, and Guatemala with initial sustained winds recorded at 180 miles per hour and gusts reaching well over 200 mph, making Mitch one of the strongest hurricanes ever. By the time Mitch reached the coast, its wind speed and rate of advance slowed considerably. Mitch covered only 600 miles in 6 days at a sustained speed of only 4 knots. Its torrential rains unleashed massive floods and mudslides with devastating results. In Honduras alone there were an estimated 6,000 deaths and 8,000 more people missing. A staggering 1.4 million were left homeless! To put this in perspective, “If the population of the United States suffered a disaster on the same scale as the population of Honduras, Hurricane

Mitch would have killed 250,000 Americans and forced one out of every four U.S. citizens from their homes” [OASDPHA, 2001].

Southern Command reported that U.S. forces reconstructed 162 miles of roads and 13 bridges, a substantial accomplishment considering the logistical challenges of operating in an inaccessible, austere environment. On the other hand, critics have said these construction projects amount to less than 2% of the highways damaged in Honduras and Nicaragua alone, and about 4%-6% of the bridges damaged or destroyed in the four affected countries [OASDPHA, 2001].

Here we have an example of measurable objectives -- the number of miles of road rebuilt and the number of bridges repaired. However, we are left wondering about the priorities of these objectives relative to other objectives. It may be that building roads, while necessary for long-term redevelopment, pales in comparison with the need for the production and distribution of potable water, for example. The other problem Southern Command’s critics bring out is we need to measure our objectives as ratios or rates relative to some established standard. For example, counting the number of people fed is only informative when we know what percentage of the population required food.

Another problem noted with some MOEs is their comprehensiveness or ability to fully measure for mission success. We may be required to implement several MOEs to completely assess how we are accomplishing the list of tasks. We want to ensure we are measuring the effectiveness of the effort as a whole and not just one

aspect of the effort or our local piece of the relief mission. Reliance on a single MOE to account for a problem with many causes is inadequate. A combination of measurements among the various agencies will ensure we are capturing the totality of the relief effort.

A second concern is sensitivity to trends. MOEs should be formulated in such a way as to collect information that will identify trends. In HA/DR operations it is often more important to note trends, such as the rate of decline in the number of dysentery cases, than simply to collect strict numbers. There is an art to choosing an MOE that measures what we want to test in a way that does not assume away tangent factors.

3. Our Choice of an MOE

Based on the preceding discussion we settled on a task-performance MOE. We will measure the ratio of neutrals fed to the total population. Admittedly, in part we have chosen this MOE because we are forced to work with the measurements that the software provides but we still believe this is an appropriate MOE and offer the following justification. The CNA suggests that MOEs meet the following criteria [CNA, 1996]:

- The MOE should relate to the overarching mission, not solely on the military task. Our ratio does that.
- Measurements should be meaningful. They should focus on the effectiveness of a task rather than on accomplishing the task. So the ratio is preferable to, say, time to complete the mission.
- MOEs should be timely or responsive to changes they are trying to measure. The ratio of the number fed is sensitive to trends.

- MOEs should be cost effective. Collecting the information to assess one's effectiveness should not put an undue burden on those providing relief. Our ratio is simple to compute given that we know the population of the affected area and can count the number of people we serve.

There are two final notes to include: established standards within the relief community and how the DOD is meeting that standard. In 1998 a global conference was held for the purpose of adopting international standards for humanitarian relief. The project is known as the Sphere Project and the result was the *Humanitarian Charter and Minimum Standards in Disaster Relief* [The Sphere Project, 2000]. This document has become the standard in HA/DR planning and execution. For example, we find that the minimum daily food requirement is 2,100 kcals per person per day. Additionally, 10-12% of total energy is to be provided by protein and 17% by fat.

When considering our MOE we reasoned through what exactly it meant to *feed* the neutrals in our scenario. The Department of Defense inventory includes Humanitarian Daily Rations (HDRs) intended to meet the standards set forth by the Sphere Project [DLA, 2003]. HDRs are designed to be culturally neutral; to provide the widest possible acceptance from potential victims of varying religious, cultural, and dietary backgrounds. Each HDR contains one day's supply of food and there are 10 HDRs packaged per case [DLA]. One medium lift military vehicle can easily carry three pallets, and each pallet holds 24 cases. So 3 pallets X 240 HDRs = 720 meals per truck.

In our scenario we have 70 neutrals, each representing a household of 8 people. So the daily requirement is 8

people per family X 70 families = 560 meals. We can see that even one truck easily meets the daily requirement. The notion is that this relief convoy would be serving several areas.

The next chapter begins with a comparison of MANA to other agent-based modeling environments. We will fully explain the motivation behind using MANA to develop our scenario. We define all of the variables used and justify the ranges we chose to vary.

III. MODEL DESCRIPTION

Having precise ideas often leads to a man doing nothing.

Paul Valery (1871-1945)
Early, 20^{th} Century French Poet

A. CHAPTER OVERVIEW

This chapter covers the genesis of MANA and how to build scenarios in MANA. We hope to leave the reader with a thorough understanding of how the model works. Our scenario, and its evolution over time, will be considered extensively. We will outline the numerous sample runs made to determine our final factor settings. Appendix B contains a detailed explanation of the model parameters along with the ranges we chose to sample. Before beginning however, a discussion of alternative agent-based modeling environments is warranted.

The author's initial concept was to set up the same scenario in three different PA agent-based programs, MANA, PYTHAGORAS, and SOCRATES [Project Albert, 2003]. Implementing the same scenario in all three environments was seen as a way to try to validate the results between programs. A good deal of time was spent setting up the scenario in the three programs; they each have strengths and weaknesses. After examination of program assumptions and experience in setting up and executing scenarios, it was deemed this approach was not feasible because of the differences in the underlying movement and personality algorithms, not to mention the differences in interactions between terrain and agents, within the models. The resulting models were very different when we used separate

agent-based approaches. MANA was selected as the program of choice based on the compatibility of its assumptions and algorithms with the research objectives.

B. AN INTRODUCTION TO MAP AWARE NON-UNIFORM AUTOMATA (MANA)

Much of the information in this section of the chapter is taken from the MANA User's Manuals, versions 2.0 and 2.1 [Stephen et al., 2002 and Anderson et al., 2003]. First we will identify why MANA was created and what types of questions are appropriate for MANA to answer. Next, we will connect our research to this tool by making clear how we intended to exploit MANA's strengths to answer our questions of interest. General squad characteristics, terrain properties, and communications are defined in the following sections. The last partition uncovers what we believed to be "bugs" in MANA.

As an overview, MANA is an object-oriented program written in the Delphi Object Pascal language. MANA files are saved as xml files making them easily transportable over the web. A single MANA run requires the xml scenario file as well as a terrain map in bitmap format.

1. The Purpose of MANA

MANA was developed by the Defence Technology Agency (DTA) of the New Zealand Defence Force. They saw the need for a simulation that was less scripted, easier to set up, and more representative of the interactions and intangibles of warfare than currently available in conventional combat models. The user's manual opens with the following statement, "The history of physics has been characterized by the search for systems simple enough to be able to be

described with a high degree of accuracy by mathematical equations." However, the developers then go on to say,

> To this day, there exists no set of equations that can with absolute certainty predict the evolution of the vast majority of phenomena we see in everyday life for any significant period into the future. Therefore, to rely on models built "on a bedrock of physics" is to deceive ourselves. It is a myth that a more detailed model is necessarily a better model, because it is impossible to capture accurately every aspect of nature. In fact, the more detailed a model is, the more obscure its workings, a problem that is compounded if the user is not the model designer. Furthermore, the non-linear nature of equations describing many real world phenomena makes them extremely sensitive to initial conditions. This means that even infinitesimal errors in describing the real world initial conditions will cause the model to make predictions that are almost uncorrelated with actual events [Anderson et al., 2003].

It was for this reason DTA developed MANA as a means of exploring complex problems.

MANA is designed to quickly build scenarios addressing a broad range of problems. The behavior of agents is decidedly not pre-potted. DTA argues that, "there seems to be a school of analysts who believe that just because they have an equation to describe some aspect of a scenario, then that aspect must be more "real" than the aspects of the scenario that cannot be so easily described." DTA's belief is that the more difficult an aspect is to describe the more important it is. So they based the development of MANA on two key ideas [Anderson et al., 2003]:

- That the behavior of the entities within a combat model (both friend and foe) is a critical component of the analysis of the possible outcomes.
- That we are wasting our time with highly detailed models for determining force mixes and combat effectiveness.

2. Why We Chose MANA

Given the nature of HA/DR operations described in the last chapter, it seemed to us that to try to explicitly model an urban humanitarian crisis would be an arduous and futile task to say the least. An agent-based approach, capturing just the essence of the problem, was certainly a more attainable objective. Furthermore, our assessment followed that of DTA regarding robustness. The complexity of HA/DR operations makes it nearly impossible to build a scenario that is even the slightest bit robust. If we attempted to model a very specific scenario, that complex model would have been necessarily scripted and, although it may have provided more concrete answers to an exact situation, would not in general give us a transportable set of concepts or enable us to extrapolate. We set out, not to find *the answer*, but to learn what is *important* when faced with a situation where a forward-deployed MEU, operating in a third world city, was tasked with a food distribution relief mission.

It is important to point out MANA’s limitations; MANA is not intended to describe every aspect of an operation. The modeler must have a clear idea of what he or she is intending to model as the scenario is set up. With a general idea of how the scenario should unfold, we began experimenting with the various parameters by trying them at

different levels. As an example of the nonlinear nature of complex adaptive systems, we observed odd behaviors of the convoy, including driving through buildings on some realizations and behaving more as expected, i.e., not driving through buildings, on others given the same parameter settings. This is just one example of the non-linear nature of CASs and characteristic of the type of behavior expected from MANA. While we were frustrated with these outcomes and tried to vary settings to force these “mistakes” out of our model, we concede the randomness and unpredictability were exactly what we desired. We wanted a medium that would allow for a great range of possible outcomes and answers. It has been this author’s experience that there is certainly not one *right way* to do logistics. Furthermore, while we enumerated general rules of thumb for HA/DR operations in Chapter II, each real situation is dependent on a huge number of variables, most of which are outside of the control of the local commander.

In the end we chose MANA because it provides a medium for assessing global outcomes resulting from thousands of local decisions. We believed this was an appropriate tool to accurately describe HA/DR operations and, particularly, the confluence of logistics and humanitarian assistance.

C. FEATURES WITHIN MANA

In this section we will present the workings of MANA as we describe in detail the evolution of our model.

1. Squad Properties in MANA

Squad parameters in MANA can be divided into four groups: personality weightings, move constraints, basic capabilities of automata, and options that affect movement characteristics.

Personality weightings determine an automata's (or individual agent's) propensity to move towards or away from something. An agent may be weighted to approach or flee from friendly or enemy units, its waypoints, easy terrain, or its final goal.

The second set of parameters deals with move constraints. Move constraints act as conditional modifiers to this process. For example, the Cluster parameter turns off an automata's propensity to move towards friends when those friends are clustered together in a greater number than some specified size. The Advance constraint prevents an agent from moving towards its next objective without a minimum number of friendly units accompanying it. Finally, the Combat constraint determines the minimum local numerical advantage a group of agents requires before they attack an enemy.

The third set of parameters describes basic capabilities of automata such as weapons, sensors, movement speed, and interactions. Closely tied to these settings is the Situational Awareness (SA) map which allows agents to communicate the position of enemy to other friendly agents.

The final set of parameters provides options on the movement characteristics of the agents, including things like whether the terrain will effect their movement, the degree of randomness when choosing a move, and if obstacles should be avoided. This final set of parameters will be induced to a greater or lesser degree depending on the type of agent being modeled.

2. Terrain in MANA

The default board in MANA is a 200 x 200 grid of cells, and there are four different types of cells representing different aspects of movement potential. Each cell can be occupied by only one agent at any given time step. The different types of cells have differing effects on movement. Some allow free movement while others completely restrict movement. Some serve as barriers to line-of-sight, provide cover or concealment, or affect the speed of an agent as it moves through the area.

Billiard Table cells are plain terrain with no special properties. Billiard Table appears black in color within the model. The second type of terrain or cell is Easy Going terrain which represents roads or other regions attractive to agents who are parameterized to prefer this type of terrain. These areas are represented in yellow in MANA. Walls, the third type of terrain, are shown in light gray. No entity may occupy or move through a Wall cell and agents cannot see through Walls if the *line of sight* feature is activated. The fourth type, Light and Dense Brush, appear green and can be set to provide varying degrees of cover and concealment as well as to have an effect on movement speeds.

Terrain is introduced into a MANA scenario by loading a bitmap into the MANA file. The bitmap could be a scenario drawn by the modeler, an actual map, a picture, or any other image translated into bitmap form. MANA agents will only recognize green, yellow, gray, and black however. The program attempts to interpret the image in these four colors and the agents will act on that translation. MANA

offers a feature called *terrain as seen by agents* that allows the modeler to determine how the bitmap has been translated into colors interpretable by the agents.

3. The Situational Awareness (SA) Map in MANA

Agents form squads and squads band together to form allegiances. Agents with the same allegiance share information by way of the Situational Awareness (SA) map shown in Figure 2. This map is a memory of the locations of enemy squads in the form of a collective picture of sensor information. As such, the SA map is always being updated by any agent within the squad who has information on the location of enemy agents. In this way, MANA portrays communication between squads and between agents within a squad.

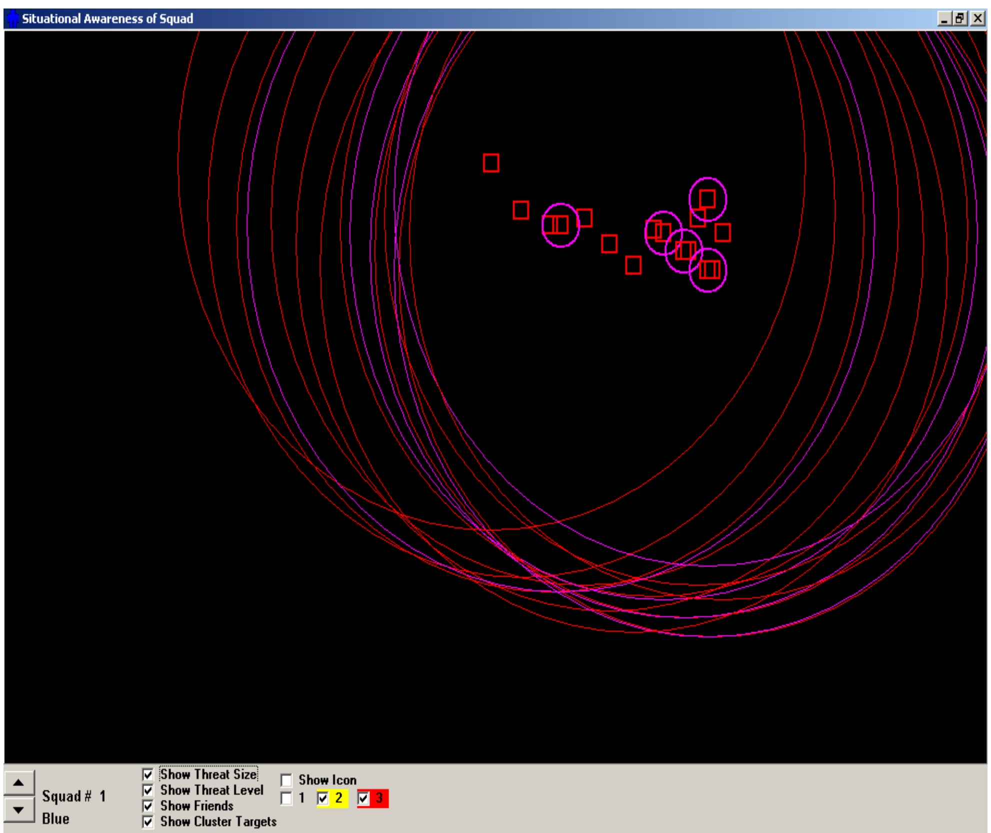

Figure 2. Sample Situational Awareness (SA) Map.

Enemy locations on the SA map are color-coded. The squares indicate the location of the enemy while the rings show their threat influence. Red represents enemy with the highest level of threat, yellow is a medium threat enemy, and light gray shows the enemy I am least afraid of. When squads are created, they are given a threat level as a characteristic and this threat level is global. In other words, that squad will appear as that level threat to any other squad not of the same allegiance. For example, it may be a squad of tanks is labeled threat level 3 whereas a squad of neutrals receives a threat level of 1.

A squad's personality parameters can be used to get entities to respond to different threat levels in different ways. MANA allows the modeler to cause agents to either be attracted to or be repelled by enemy agents of particular threats. Furthermore, we have the latitude to pursue any of the threats more or less vigorously by manipulating an agent's personality parameters.

MANA uses the *threat persistence* parameter to specify how long a sighting will remain on the SA map. This factor is a way of indicating the transient nature of intelligence. After some time, intelligence may become unreliable. Caution must be exercised when varying this parameter because the longer the *threat persistence* the larger the number of sightings that will remain on the SA map. There is the potential for information overload.

The circle around an agent on the SA map, as shown in Figure 2, shows the region in which that agent will react to an enemy. For example, just because an automata knows

an enemy is present at a certain location does not automatically mean the agent will react to that enemy. Only when an enemy enters the circle will a reaction be triggered. This allows agents to keep their distances from known enemy positions, without necessarily running away from them. Likewise, if an agent's personality is such that it chases enemies, *threat influence* represents how close that enemy needs to be before the agent will bother chasing. The *threat influence* parameter lets the modeler specify this range at which action will be initiated.

4. "Bugs" in MANA

We encountered three main problems with the model. The first was simply a clarification which should be made to the documentation. In the user's manual *threat influence* was presented as the radius of the ring around an agent which will induce another agent's action. In other words, if a truck agent's threat influence ring is larger, neutral agents will respond differently than if the ring is smaller. In reality, this ring will induce the actions of the agent owning the ring. A larger threat ring around the truck will cause that truck to react differently than if the ring were smaller.

We stumbled upon our second problem when we made runs for our full model. MANA's user manual indicated the range of the *precision* parameter was from zero to 1000. We found if we entered zero locally, MANA would default and put a value of one in its place. Prior to discovering this, we sent off our design to be run on the supercomputing cluster with the lowest *precision* design point set to zero. Our results indicated, when the model was running in batch mode, MANA did not default the setting to a one. At this

point the problem is being researched and we do not have a conclusive answer as to what happens in batch mode.

The third problem we discovered early on; it has since been corrected. This problem was in the way the movement algorithm had been coded. MANA used three digits to calculate speed; call them YXX. If XX was 00, then the agent would move Y spaces with 100% probability but if XX was anything other than 00, then the agent would move Y + 1 space(s) with probability XX%. So a speed setting of 050 would cause an agent to move zero spaces 50% of the time and one space 50% of the time. But a speed of 150 produced a counterintuitive effect. It meant the agent would move zero spaces 50% of the time and two spaces 50% of the time. The speed settings have since been changed to be strictly increasing, so that an agent whose speed is 150 will move one space 100% of the time and an additional space 50% of the time.

A little further discussion is warranted. We found it appealing that there was randomness in the way MANA calculated movement. When we thought about what affect this algorithm might have on convoy movement behavior we noted it allowed for stuttered, variable movement rates rather than strictly constant speeds. We believe stops-and-starts more appropriately depict movement of vehicles, and individuals for that matter. On the other hand, setting the movement speed too high will cause entities to “jump” ahead several grids in a single time step with the effect being that they pass through walls or go undetected by other agents. This we did not want so we considered our

movement speeds very thoroughly and chose parameter values which would not allow for this possibility.

D. OUR URBAN, HA/DR SCENARIO SETUP IN MANA

This section will provide a detailed description of our scenario and then explicate the specifics of each squad. Appendix B provides a comprehensive listing of the parameters, how they are manipulated within MANA, and what we believe they represent in the “real world”. Furthermore, the appendix provides justification for the ranges we chose for each of these factors. While reading through this model description, we suggest the reader refer to Appendix B as well.

The scenario, shown in Figure 3, depicts a convoy operating in an urban environment. The convoy follows a given route to the southern HA site where they distribute food to neutrals who have made their way to that site. The simulation runs for 1000 time steps and we do not vary this in any of our runs. Each run begins slightly differently because of the random placement of squads within a defined border at the start of the run. These random starting locations are reset each run. Figure 3 shows the scenario just after starting a run.

Figure 3. Beginning of a Run.

In Figure 4 Blue agents, representing a convoy of Marines (or a relief agency with a Marine security escort), drive across the top of the screen until they come to their first waypoint, represented by a blue flag. They make a left-hand turn and continue south. The yellow agents are neutrals. The northern neutrals are making their way to the HA site closest to them, represented by the yellow flag in the center of the upper screen. Concurrently, southern neutrals move towards the southern HA site. The red agent is searching for the convoy and intends to fire at the Marines and then quickly run away. Figure 4 depicts the action of the aggressor.

Figure 4. Convoy passes northern neutrals; they begin to chase. Aggressor takes a shot at the convoy.

If the trucks pass within the northern neutrals *threat influence* ring they will speed up and try to follow the trucks. As the convoy is passing by, the red agent will take a shot and then try to run away. If the security element can identify the aggressor it will return fire. The convoy's response will be to speed up and drive out of the area. The convoy will eventually make their way to the southern HA site and begin feeding the neutrals. This is shown in Figure 5.

Figure 5. The convoy feeds neutrals at the southern HA site.

In the next section we will step through the process of how we built our squads in MANA. We have five squads: a convoy of four trucks; the security attachment, a single vehicle; 35 northern neutrals; 35 southern neutrals; and the red agent.

1. Squad General Properties Tab

Creating a squad in MANA begins on the squad general properties tab (see Figure 6). Here we name the squad, set the number of agents in the squad, establish the starting position, place the waypoints the squad will follow, and set up features relating to how the squad will appear on the SA map.

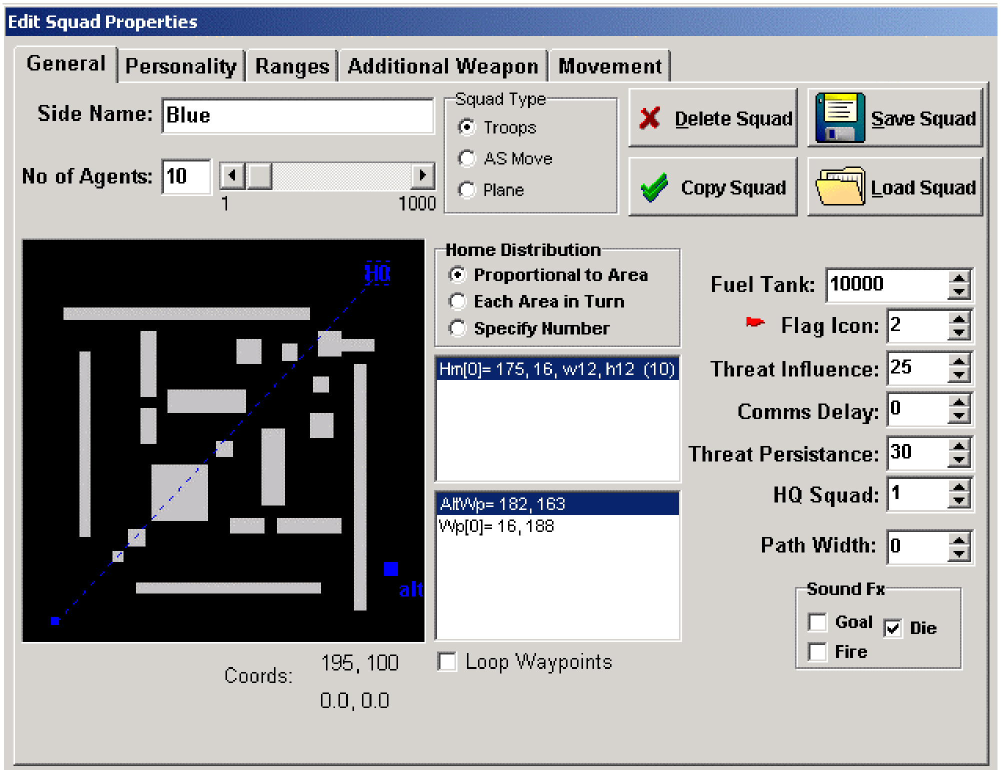

Figure 6. Sample Squad General Properties Tab

We establish starting points by first drawing a starting box. Next, we specify the (x, y) coordinates of the center of that box and define the height and width. Agents are then randomly placed anywhere within the box at the start of each run. In our model we set up two such boxes; one in the upper half of the screen and the other in the lower half. Our northern and southern neutrals begin each run in those boxes respectively. The aggressor agent has the run of the entire screen as a starting location. Right at the start of the scenario we have introduced random starting locations for the neutral agents and believe this effectively describes our urban scenario.

The convoy always starts in the upper right-hand corner and follows a prescribed route to the southern HA

site. Marine Corps doctrine requires the Convoy Commander to plan the convoy route prior to stepping off. Predetermining the route allows leaders to plan for actions to be taken at choke points, rehearse timing, plan on-call targets, coordinate communication signals, and determine appropriate road march and catch up speeds. Setting waypoints in our scenario is akin to determining the convoy route. The only other waypoints used were set at each of the HA sites as a means of attracting the neutrals to these sites.

There are two other points to make about the Squad General Properties Tab. First, the *comms delay* parameter allows the modeler to dictate the number of time steps it takes before enemy detections appear on the SA map. This represents a delay in processing and communicating incoming information. Because we set our scenario in an urban environment we considered communications as simply word-of-mouth. As such, communication would be imprecise and slow, relative to a defined communications network. On the other hand, there were a large number of neutrals posting information to the SA map so we did not think this parameter would make much difference after the initial sightings. To test all of the possibilities we varied the length of time until postings widely.

The second feature to draw attention to is the means in which MANA combines information. The *HQ squad* identifier indicates the hierarchy among squads. All squads of the same allegiance with the same HQ squad share the same SA map. This allowed us to align the red agent

with the mass of neutrals. We wanted to get at the idea that the aggressor could easily blend in with the crowd.

2. Squad Personality Properties Tab

The personality properties tab is where we set the personality weightings that drive automata toward or away from goals, friendlies, or enemies. The other basic feature on this tab is the move constraint settings that modify movement propensities by restricting or constricting them. Figure 7 captures this tab and Table 1 describes the weightings in more detail.

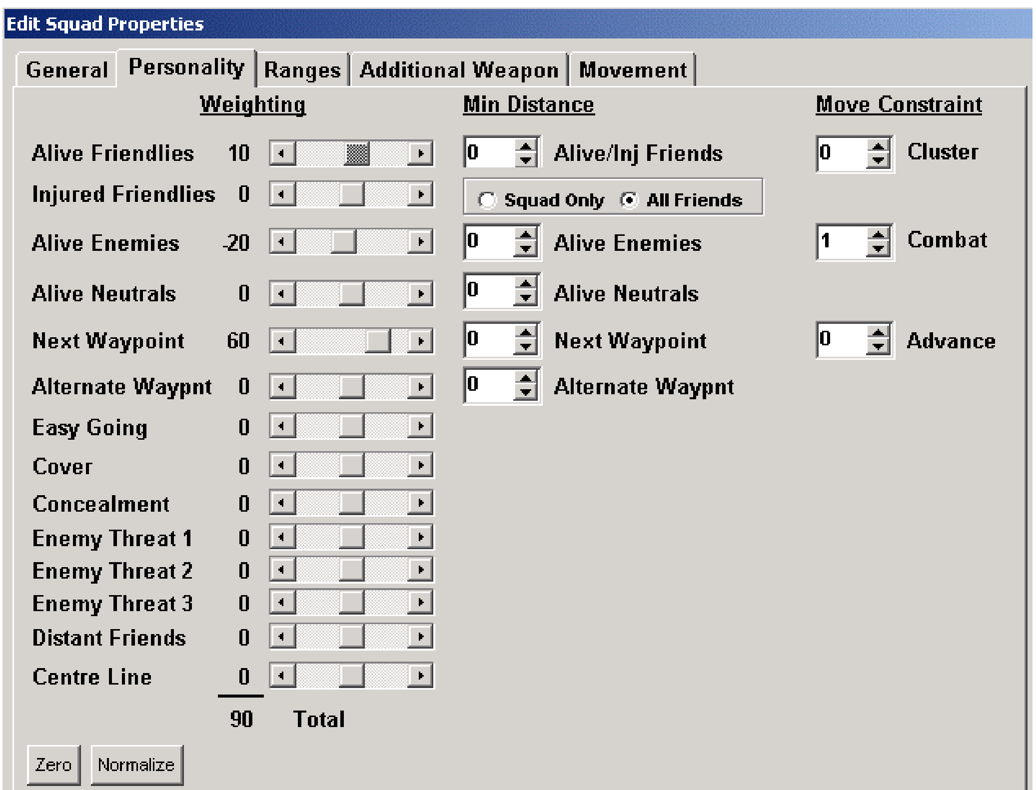

Figure 7. Sample Squad Personality Properties Tab

Description	**Controls propensity to move toward/away from**
Alive Friendlies	Agents of same allegiance within sensor range
Injured Friendlies	Injured agents of same allegiance within sensor range
Alive Enemies	Agents of enemy allegiance within sensor range
Alive Neutrals	Agents of neutral allegiance within sensor range
Next Waypoint	The next waypoint agent's squad has been assigned
Alternate Waypoint	The alternate waypoint agent's squad has been assigned
Easy Going	Areas with easy going within 5 pixels of agent
Cover	Areas with protection from fire within 5 pixels of agent
Concealment	Areas which improve stealth within 5 pixels of agent
Enemy Threat 1	Enemies in SA map which are of Threat Level 1
Enemy Threat 2	Enemies in SA map which are of Threat Level 2
Enemy Threat 3	Enemies in SA map which are of Threat Level 3
Distant Friends	Agents of same allegiance anywhere on map
Center Line	The center line (defined as line between the current and immediately past goal)

Table 1. Squad personality weighting variables.

We have modeled the convoy with weights that pull them toward their waypoints and toward one another. After many, many hours of experimentation, we discovered these two factors provided the most control for getting the convoy to accomplish its mission. In our full model we varied the weights of these two parameters in order to indicate differing levels of unit cohesion and discipline. Additionally, we were interested in seeing what would happen if we strengthened their attraction to injured members of the squad.

The neutrals on the other hand were much more loosely weighted. We generally wanted them to go toward the HA site and prefer to stay together but neither of these weightings was particularly strong. The northern neutrals' desire to chase the convoy was accomplished by increasing their attraction to the convoy and zeroing out their impetus toward the northern HA site once contact was made. Initial runs provided the range of values we studied in our full model.

The aggressor agent had, as his main objective, the convoy. Depending on whether he had taken a shot or not, he was drawn toward the trucks or repelled from them. Before the shot we had him seek out the convoy. Once the red agent had fired, his weighting changed to a negative value, the result being that he "ran away." Additionally, the aggressor wanted to hide among friends, accomplished by an attraction toward friends weighting, and opted for easy terrain, cover, and concealment when fleeing.

Next we will treat the minimum distance and movement constraints. These provide modifiers on the personality weightings. For example, the *min distance to alive enemies* variable limits the distance to which an agent will approach an enemy. The value entered is the minimum distance the agent will try to maintain in terms of number of cells. We did not use any minimum distance settings in our scenario.

The constraints come in three types. The *cluster constraint* is intended to prevent the build up of clusters of friendly entities above a certain size, determined by the value of this parameter. *Combat constraints* prevent a

squad from advancing on an enemy without a numerical advantage. MANA counts the numbers on each side within sensor range, than compares the two numbers. For example, a value of 5, input here for a blue squad, means there must be 5 more blue agents than red before blue will advance. Finally, the *advance constraint* works in the same way to prevent a squad from advancing toward its next waypoint without a sufficient number. We did not invoke any of the constraint parameters.

3. Squad Range Properties Tab

The squad range properties tab, Figure 8, is divided into the following four sections: general information about the squad; sensor range; fuel information; and parameters controlling enemy interactions.

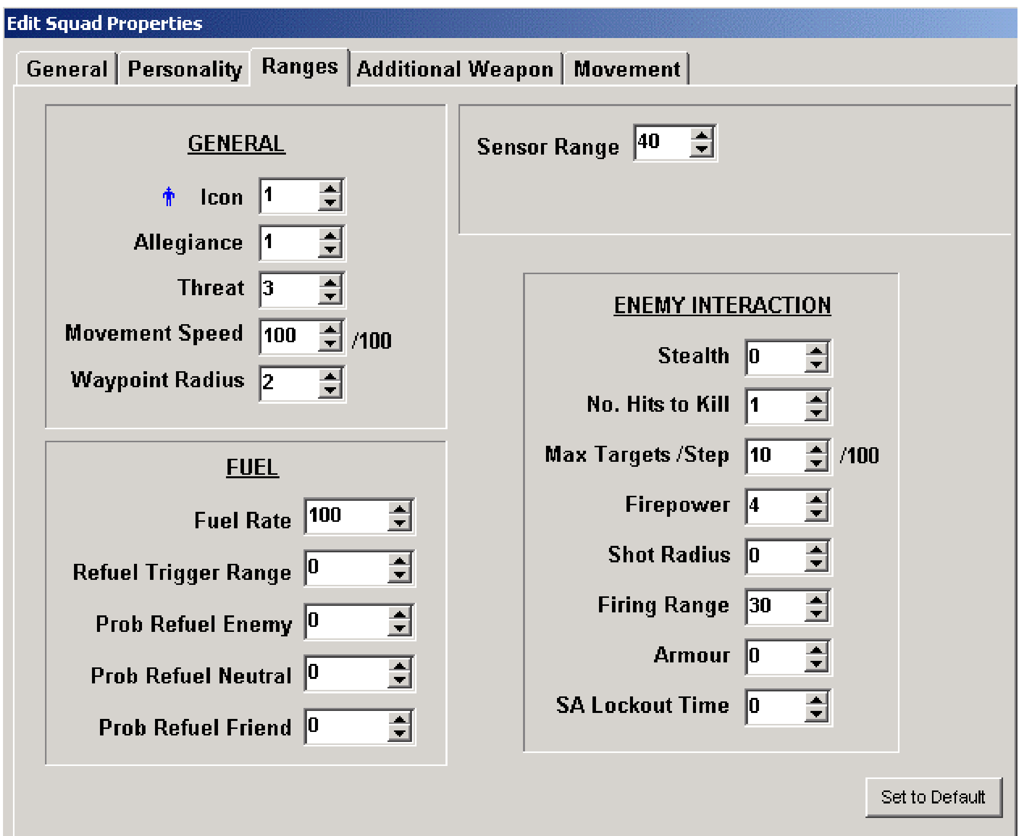

Figure 8. Sample Squad Range Properties Tab

The general information lets the user select an icon for the squad, assign its allegiance, establish the threat level which will appear on an enemy SA map for that squad, specify the squad’s movement speed, and dictate how close the squad must come to its waypoints. We will dwell on the movement speed briefly. We felt from the very beginning the convoy’s speed should be no more than four times the speed of the neutrals. This was partly based on real world assumptions and partly on MANA peculiarities explained in the next paragraph.

We wanted to encourage the northern neutrals to chase the convoy. After all, the intent was to feed as many neutrals as possible. We began with the assumption the average walking speed of the neutrals should be around 3 mph based on the author’s Marine Corps experience where we set our march rate at between 2.5 and 3 mph. Since there is no way to explicitly code 3 mph we made the neutral speed and convoy speeds relative to one another. So through our judgment we set the convoy speed at 4 times the northern neutrals’ walking speed and made variations around these starting values.

The other oddity we needed to work around was the number of time steps used in the scenario. The faster we set the speed of the convoy, the quicker they reached the HA site and shut down while they conducted feeding operations. It would not do to have the convoy reach the HA site within 10 time steps, for example, and then sit there for another 990. So we needed to choose a range of

speeds that made sense and did not require us to change the run time for different speeds.

Continuing on with the squad range properties tab, the fuel variables attracted much of our time and effort during the initial setup as we searched for a way to directly measure logistics support. The variables were *fuel tank,* the amount of fuel with which an automata begins the run; *fuel rate,* the amount of fuel consumed per time step; *refuel trigger range,* within this distance an entity may be refueled; and *probability to refuel neutrals, friends, or enemies,* the probability that one of these agents, within the refuel trigger range, will be refueled. Our preferred choice for an MOE would have been to use these parameters as a means of measuring food distribution more specifically and more accurately. We intended to begin the scenario with each neutral having a set amount of "food" and would have decremented that food with each time step. We would have then set the *probability to refuel neutral* parameter in such a way as to cause the convoy to pass food to the neutrals. This would have allowed us to measure the amount of food delivered relative to the need. After many hours of work in an earlier version of MANA we were unable to set this up. The current version of MANA allows a form of this but we have not gone back to reset our scenario. This type of analysis will be one of our recommendations for further work.

Now we discuss the enemy interaction set of parameters. *Stealth* is intended to represent how difficult it is to see an entity once it is within an enemy's sensor range. The red agent invokes this factor after taking a

shot at the convoy. We varied the *number of hits to kill* parameter in order to model various types of armor protection on the convoy. If this factor is set to any number greater than one, the model labels an entity sustaining the first hit as injured thereafter.

Max targets per step is the number of targets within sensor and firing range that can be engaged per time step, divided by 100. Dividing the number allows for fractions of targets and works in the same way that movement speed is calculated. So a 150 setting means that one target is engaged with 100% probability and a second target is engaged 50% of the time. We used this variable to model the type of weapon the red agent carried; single shot or automatic. The aggressor's *firepower* value, or single shot kill probability (SSKP) was varied over the entirety of the range. We reasoned that he could choose the time and place of his shot on the one hand but, on the other hand, his shots would be poorly aimed. The Marine's return fire was considered to be fairly inaccurate though because they would be reacting instinctively, without complete information on the source of the shot, and while trying to drive out of the kill zone.

We considered varying the *firing range* factor but, in the end, thought that realistically the canalizing effect of the streets, as well as the built up nature of urban terrain would limit the effective range of any type of weapon to the line of sight range of the shooter. Therefore, we set all weapons' ranges and did not change them throughout the runs.

Finally, we wanted to model the differences that different types of weapons would have on mission success. What would be the difference if the red agent carried a rocket propelled grenade versus an AK-47. The *shot radius* variable sets the radius of the SSKP. *Shot radius* then allowed the introduction of area fire weapons in addition to point direct weapons. It should be noted that an agent will not fire an area fire weapon unless that agent is outside of the range of the blast radius. However, if the weapon is fired, friendlies may be injured just the same as enemy agents.

4. Squad Movement Tab

The final tab is the squad movement tab, Figure 9, which allows the analyst to choose between movement algorithms, set the degree of randomness when moving, and dictate squad movement characteristics. As indicated earlier, we uncovered a problem with the *move precision* parameter. Move precision sets the degree of random motion when choosing a move. When we set the factor to zero in batch mode we broke something in MANA, as yet unknown.

Navigate obstacles will make entities in the squad try-and find their way around solid obstacles when they get “stuck.” *Squad moves together* means the fractional movement for each squad member is the same at each time step. *Going affects speed* means entities will decrease their movement speed with regard to the type of terrain they are in. As you can see, these are check boxes and we did check these in our runs.

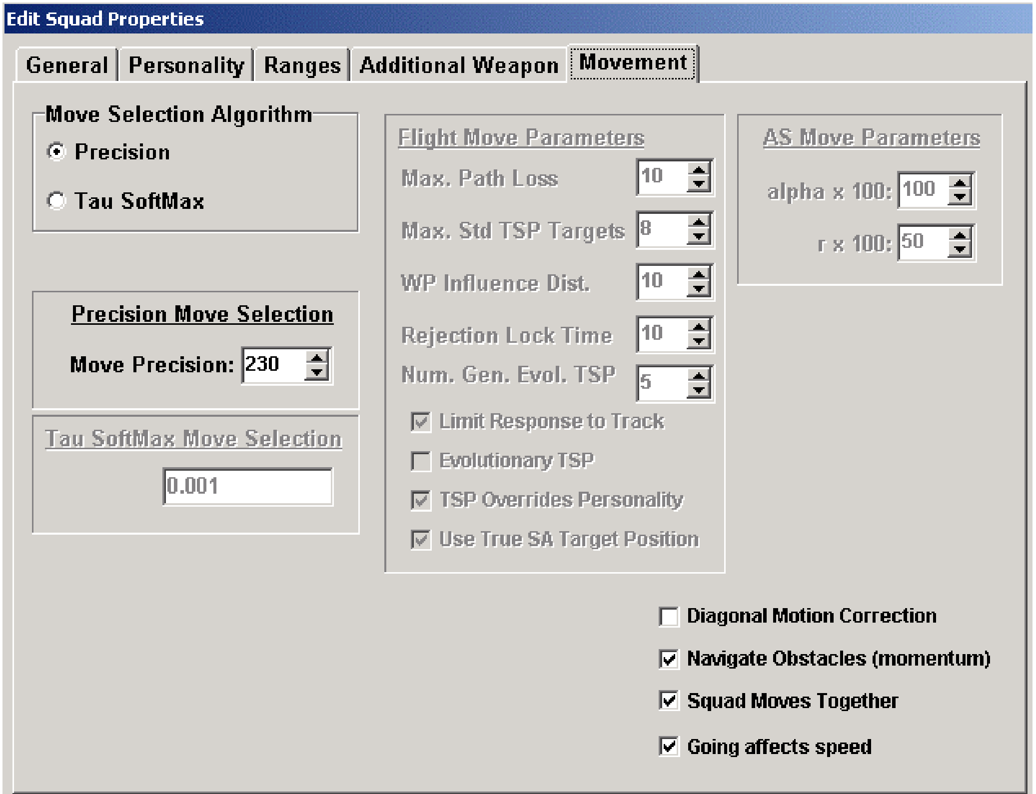

Figure 9. Sample Squad Movement Properties Tab.

5. Trigger States

Trigger states, shown in Figure 10, are a way to change the properties of a squad in the middle of a run based on the occurrence of some event. All entities start in the default state, and remain in that state until a triggering event occurs. Triggering events may change the behavior of the particular agent involved in the event or may change the behavior of the entire squad that that agent belongs to. Once activated by the causal event, the agent's behavior will change in a way, and for a duration, specified by the modeler. For example, in its default state the red agent wants to move towards the convoy. We used the *taken shot* trigger to change his behavior to "running away" from the convoy.

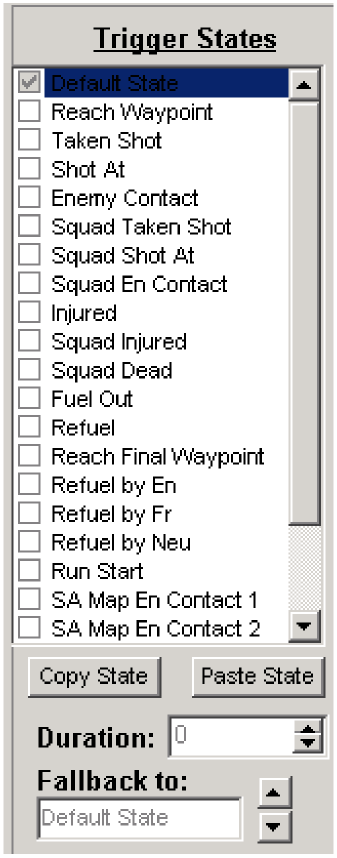

Figure 10. Sample Trigger States in MANA.

Duration is the number of time steps a squad or agent will remain in that trigger state. The *fallback to* option indicates what state the agent *will* fallback to when the specified number of time steps has expired.

Beginning with the convoy, we invoked two trigger states in addition to the default state. First, we increased the convoy's speed and desire to move away from an enemy when the *squad shot at* trigger was activated. This is in line with Marine Corps doctrine when caught in a near ambush. Secondly, when the convoy reaches the southern HA site, triggering the *reach final waypoint* state, their movement speed is set to zero and they

recognize the neutrals as enemies which has the effect of causing the convoy to begin firing HDRs at them.

The northern neutrals' single trigger was seeing or hearing of the presence of the convoy; *enemy contact*, communicated through the SA map. This event caused them to forgo their initial desire to make their way to the northern HA site and, instead increase their speed and desire to follow after the trucks. We believe this accurately describes how crowd movement patterns might look in a real world HA/DR operation.

Two trigger states were concatenated together to portray the aggressor's actions after taking a shot. First, he enters the *taken shot* state for a single time step. This is simply a MANA trace-back application trick to allow us to determine what happened when those actions occurred. Next, red falls into the *retreat* state while he flees from the convoy. We did not intend for this to be a combat model but did want to introduce the idea of harassing fire and believed the single red agent was the best way to inculcate that construct.

This chapter, along with Appendix B, completes the details of the setup of our model in MANA. We believe that between the combination of the default squad weightings, the trigger states, and the parameter settings that they invoke, we have a good distillation of the HA/DR scenario we desired. We also believe that this model is general enough to allow for a number of different extrapolations. For example, the convoy could easily be copied and reintroduced as a second convoy tasked with feeding a second site. Similarly, we could increase the number of

red agents to test the construct of a more hostile populace. Coordination between neutrals could be tested by strengthening their attraction to one another, by setting their movements to be more precise, or by manipulation of SA map settings.

The next chapter explains the Latin Hypercube design used establish parameter settings in our experiment. Next we consider the statistical tests we used to fit equations to the resulting data.

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IV. ANALYSIS METHODOLOGY

Without data and information there can be no monitoring. Disaster data are numbers that matter.

Christopher Black

International Federation of the Red Cross, 1997

A. CHAPTER OVERVIEW

We present our analysis methodology in three parts. Section B devolves how we designed our experiment. In this discussion we plainly identify the 40 squad/state/factor combinations, described in Chapter III, we chose to include in our experiment. Secondly, the process of designing a Latin Hypercube (LHC) is explained as we applied the technique to our combinations. In Section C the statistical software package we used for our analysis is introduced. The final division (Section D) explains the principals behind the additive multiple regression model we fit to our dataset, as well as, the underlying assumptions necessary for the regression technique to be valid. Finally, the statistical tests used to compare various regression models and to identify significant squad/state/factor combinations are explained.

B. DESIGN OF EXPERIMENT

We now highlight three topics; the selection of factor combinations for the experiment, an explanation of the experimental design used to generate squad/state/factor combination settings, and the supercomputing process that returned the dataset used in our analysis.

1. Squad/State/Factor Combinations and Their Ranges

Because it is possible in MANA to vary the parameters of any squad, in any state, the number of combinations can grow almost without bounds. We used thousands of exploratory MANA runs to bound the combinations we wanted to test. For example, we wanted to find the effect that the *number of hits to kill* parameter had on the number fed. We reasoned if a truck were killed, fewer neutrals would be fed. But it was not necessary to vary this parameter when the convoy entered the *shot at* state because the red agent would be running away at that point. A full factorial design was not needed. Instead, squad/state/factor combinations were selected based on an understanding of the problem. In the end, we found 40 combinations we thought should impact the number of neutrals fed.

Table 2 lists the 40 combinations explored and the ranges we chose to vary. The ranges were also determined through trial and error during the thousands of exploratory runs. The naming convention we used was squad_state_factor. In some cases the parameter value is set at the outset of a run and is not identified with a particular state, but rather is carried throughout the run. In this case the naming convention is squad_factor; see for example southern neutrals_ThreatRate in the table.

squad	state	parameter	low	high
Convoy		ThreatRate	1	500
	Default State	Alive Friends	50	100
		Next Waypoint	80	100
		Movement Speed	50	200
		No. of Hits Required to Kill	1	3
		Min Distance to Friends	3	15
	Squad Shot At State	Alive Friends	50	100
		Alive Enemy	-100	-50
		Injured Friends	-25	25
		SA Threat 3 (High)	-100	-50
	Reach Final Waypoint State	Max Targets Per Step	80	120
southern neutrals		ThreatRate	1	500
		CommsDelay	0	500
		Precision	0	500
	Default State	Next Waypoint	60	80
Security		ThreatRate	1	500
	Default State	Next Waypoint	80	100
		Movement Speed	50	200
		No. of Hits Required to Kill	1	3
northern neutrals		ThreatRate	1	500
		ThreatSize	5	100
		CommsDelay	0	500
		Precision	0	500
	Default State	Next Waypoint	60	80
		Sensor Range	5	100
	Contact State	Alive Friends	0	50
		Alive Enemy	50	100
		SA Threat 3 (High)	50	100
		Sensor Range	5	100
Aggressor		ThreatRate	1	500
		ThreatSize	5	100
		Precision	0	500
	Default State	SSKP	0	100
		Alive Enemy	50	100
		SA Threat 3 (High)	50	100
		Sensor Range	5	100
		Max Targets Per Step	100	300
		Shot Radius	1	30
	Retreat State	Alive Enemy	-100	-50
		SA Threat 3 (High)	-100	-50

Table 2. Squad_state_factor combinations and their ranges used in the design of experiments.

2. Latin Hypercube (LHC)

Obviously we could not have conducted any type of full or even fractional factorial experiment. If, for example, we had looked at our 40 combinations at even two levels

each, we would have begun with 2^{40} design points requiring $1.0995x10^{12}$ runs to obtain even one data point for each of the possible combinations. On top of that, if we then considered running the experiment numerous times at each design point, varying the seed each time, the amount of time it would have taken to run our simulation would have risen exponentially. A three level experiment, enabling us to detect non-linearities, was right out.

So then we turned to the LHC design. A LHC is a sampling technique whereby all portions of the distribution of the range of a factor are divided into strata of equal marginal probability. The LHC then samples once, at random from within one of the strata. The value drawn is then assigned as the factor setting for the first run of the simulation. This technique is then repeated without replacement for the second, third, and all subsequent runs. So by the end of the LHC process the distribution of possible values for that factor have been uniformly sampled resulting in a column filled with randomly sampled and randomly assigned factor settings that cover the number of simulation runs [TRAC-Monterey, 2003 and Cioppa, 2002]. When the technique is applied to all factors the result is a square matrix with sides equal in length to the number of factors.

We used the java code given in Appendix C and written by Professors Susan and Paul Sanchez to select settings for our LHC. The input to the ReadFactors class is a three-column spreadsheet. The first column is the factor name. Columns two and three are the low and high settings, respectively, for that factor. ReadFactors calls the

LatinHypercube class and passes it the spreadsheet information. Class LatinHypercube actually generates the LHC. Precautions were built in to deal with the case where the factor range was less than the number of factors.

If, for example, the factor only had three settings but the designer wanted to include 30 factors, the code would try to divide the range of that three-settings parameter into as many bins as possible and then select equally from each bin until the factor's column in the LHC was full. The result would be approximately 10 of each of the settings randomly assigned throughout the LHC.

With a LHC design one wants to limit the incidence of multicollinearity or correlation between the columns. The very fact that values within each column are chosen at random is, in itself, a guard against confounding but it is still possible for correlation to enter into this design nonetheless. In order to try to minimize the chance of multicollinearity occurring in our design, we strung 16 LHCs together. By concatenating 16 LHCs, each of which had randomly generated columns, the chance of any two columns being correlated was much less than would have been the case in a smaller design. This was a simple process because the java code allowed us to specify how many LHCs we desired to be concatenated together.

Our design process followed the protocol just described. Initially we started with four LHCs appended together to avoid the problem of multicollinearity. After our first run we had a 160 x 40 matrix. A correlation matrix of the results showed that in several cases we had correlation between columns which was greater than 0.20 or

less than -0.20. The highest correlation was around ± 0.27, and the average correlation magnitude was 0.063. We wanted to force more of this correlation out of our design so we eventually strung 16 LHCs together for a total design space of 640 x 40. This gave us 640 different combinations of settings for our 40 squad/state/factors. We were confident our design was sufficient to cover the range of possible outcomes and were pleased with a final correlation of not more than ± 0.14 with an average magnitude of 0.031.

3. Supercomputing

PA has established a web-based interface where modelers may submit their agent-based files for runs on the supercomputing clusters at the Maui High-Performance Computing Center (MHPCC). Using this resource simply requires one to submit the xml file and bitmap, and then define the variables to be farmed over, along with the ranges and step size for each of those variables.

In our case, because we were not using standard step sizes to fill out our ranges, we conferred directly with the MITRE Corporation, the principal contractor supporting the Marine Corps' efforts. Our LHC design required MITRE to write a front-end script that would strip off row values from our spreadsheet and insert them into the xml file. They then farmed the runs over a supercomputing cluster and ran each set of design points 50 times, varying the seed with each run. With 640 design settings and 50 replications at each row they completed 32,000 runs in 7 ½ hours. The results were returned to us in the form of a comma separated values (.csv) file.

C. DATA ANALYSIS

In this section we introduce the software package we used to analyze that data. Next, we relate why we chose to consolidate our data prior to beginning our analysis.

1. JMP Statistical Discovery Software™

To begin looking at the dataset, we needed to find a data analysis package that was easy to use and which had well-developed graphics capabilities. We felt the graphics capability was especially important because of the need to effectively view the breadth of the sample space. We could have used several different sets of software and migrated the results from one to another but opted instead, to look until we found a system offering one-stop-shopping. The JMP Statistical Discovery Software™ package met our needs.

JMP is a product of The SAS Institute® and is advertised as a software package for interactive statistical graphics [JMP, 2002]. JMP includes:

- A spreadsheet for viewing, editing, entering, and manipulating data.
- A broad range of graphical and statistical methods for data analysis.
- Options to select and display subsets of the data.
- Facility for grouping data and computing summary statistics.

The software is designed to be a point-and-click product made for the field analyst. We found this software easy to learn and use.

2. Data Rollup

We began our regression model fitting efforts with the full dataset, 32,000 points. Because we had so many data

points, it was hard to determine if a particular outcome was the result of the true characteristics of a variable or simply due to the natural variability of that factor. We decided we would average the results of the 50 iterations at each set of design points. We used the mean of the consolidation as the result for that particular set of runs. This technique also allowed us to invoke the Central Limit Theorem.

D. ADDITIVE MULTIPLE REGRESSION ANALYSIS

While there are many analysis techniques that could have been applied to our dataset, we concentrated primarily on additive multiple linear regression. We wanted to drill deeply into understanding the effect our 40 combinations of squad/state/factor had on mission success. This included trying to quantify that effect to a limited degree but, more importantly, involved finding a robust set of parameters which would be effective over a wider range of scenarios.

Additionally, we hoped to determine what the combination suggested in terms of real world outcomes. If, for example, convoy speed turned out to be statistically significant, what were the training, tactics, and techniques ramifications? We felt this was an area of high contribution stemming from our research.

Regression is a standard technique that quantifies how a response variable is perturbed by various predictors. Mostly, we used linear regression, the application of regression techniques to a continuous response. In some cases we treated individual inputs as ordinal in order to

track specific effects of interest. We considered only main effects, 2nd degree polynomials and 2-way interactions.

1. The Regression Technique

The regression technique fits a linear function line (or set of hyperplanes in the case of multidimensional input data) using the least squares fitting criterion; minimizing the sums squared error on a set of continuous, categorical, or independent variables. A random error term (ε) is included so the general additive multiple regression model looks like this:

$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k + \varepsilon$, where

Y is the dependent variable,

the x's are the independent variables,

β_i is the coefficient of the independent variable with i = 1,…,k, and

ε is a random error term.

2. Assumptions

The following assumptions regarding ε must hold for the regression fitting technique and the statistical testing procedures (t-tests and F tests) to be a valid [Devore, 2000 and Hamilton, 1992].

- Errors must follow a normal (Gaussian) distribution.
- The errors must be identically distributed with zero mean and constant variance.
- All errors must be independent and identically distributed (iid).

3. Comparing Regression Models

We used the coefficient of determination, or R^2, as our principal measure of best fit when deciding between

regression models. The R^2 value estimates the proportion of the variation in the response around the mean which can be attributed to terms in the model rather than to random error [JMP, 2002]. So an R^2 of 1.0 means the response is completely predictable based on the value of the independent variables. An R^2 of 0.0, on the other hand, means the fit predicts the response no better than the overall mean would. Because R^2 will never decrease as more variables are added, we were not interested in a model that maximized R^2. Instead we wanted to find a simple regression model, one with the fewest number of factors, for which R^2 was nearly as large as the R^2 of a “full” model which included all 40 squad/state/factor combinations. R^2 is calculated:

$R^2 = 1 - \frac{SSE}{SST}$, where

$$SSE = \sum (y_i - \hat{y}_j)^2 = \sum [y_j - (\hat{\beta}_0 + \hat{\beta}_1 x_{1j} + \cdots + \hat{\beta}_k x_{kj})]^2$$

and

$$SST = \sum (y_i - \overline{y})^2$$

we refer to SSE as Sum Squared Errors and SST as Sum Squared Total.

Our second comparison measure between models was the F statistic, also known as the *model utility test*. If l is the number of terms in our original regression model and k is the number of terms in a model including the original terms plus interactions, than the F test involves the null hypothesis $H_0 : \beta_{l+1} = \beta_{l+2} = \cdots = \beta_k = 0$, according to which there is

no useful relationship between Y and any of the k predictors. If, however, at least one of these $\beta's$ is not 0, the corresponding predictor(s) are useful. The test is based on a statistic having an F distribution when H_0 is true as defined by:

$$f = \frac{(SSE_l - SSE_k)/(k-l)}{SSE_k/[n-(k+1)]}$$

where SSE_k is the unexplained variation for of the regression model having k terms and SSE_l is the unexplained variation of the reduced model [Devore, 2000].

4. Plotting the Regression Models

Once we were satisfied with our choice of a regression model, we used two plots as a quick validation of the goodness of fit of that model. First, we plotted the actual number fed vs. the predicted number fed in order to visually check the fit of our prediction line. This technique serves as an easy and immediate way to visually ensure predictions follow the general pattern of the actual dependent variable. In the actuals vs. predicted plot we hoped to see our points lining up diagonally, beginning at the origin and following a slope of one. If the predictions were perfect, they would have lain entirely over the top of the actual number fed at each data point in our dataset. See Figure 11 as an example. This type of pattern would have visually indicated that our estimated regression function was a good fit.

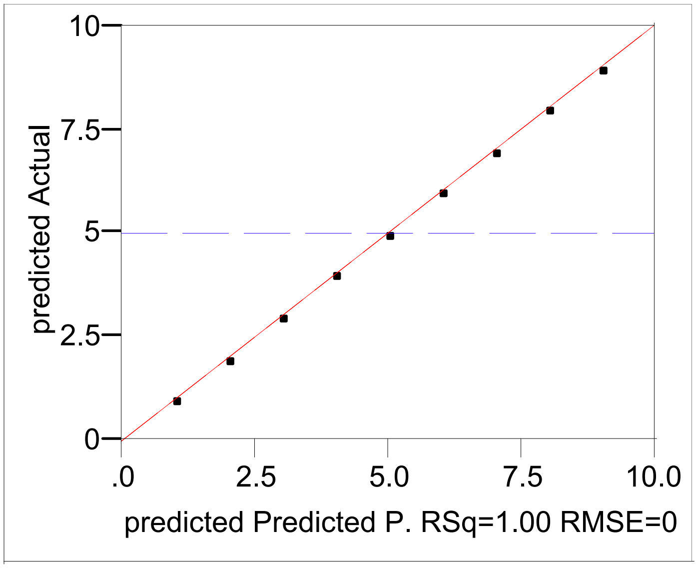

Figure 11. Sample of actual vs. predicted plot.

A second quick-look plot we used was the standardized residuals vs. the predicted number fed plot. Residuals are the difference between the actual number fed and the predicted number fed. In this plot we hoped to see the points evenly spaced and distributed throughout the frame, as in Figure 12. In other words, we did not want to be able to detect any pattern. A pattern would violate the assumption that errors were independently distributed with constant variance [Devore, 2000].

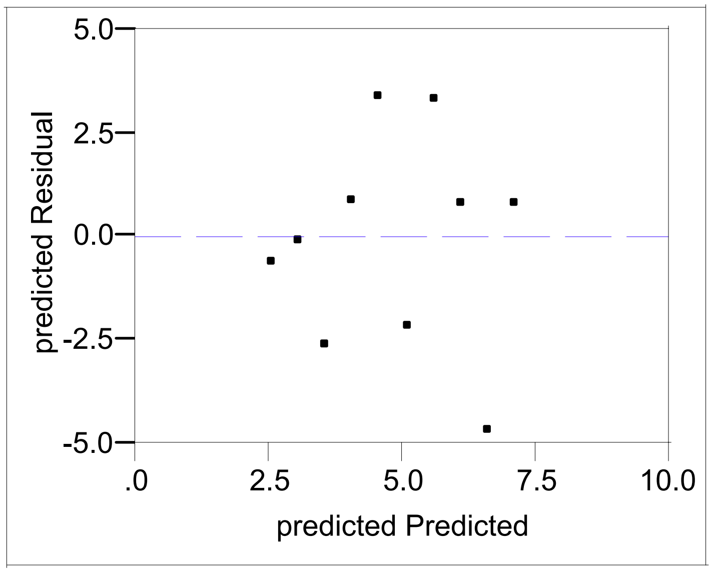

Figure 12. Sample residuals vs. predicted plot.

5. Determining the Significance of Terms in the Regression Model

The final step in fully accepting the specific combinations of factors themselves was to test them both qualitatively and quantitatively. Qualitatively, the author’s judgment was relied upon to determine whether the inclusion or exclusion of a specific squad/state/factor combination made *sense*. For example, in the opinion of the author, should the movement speed of the convoy be included as a factor in predicting the number of neutrals fed in our scenario? Or, should the sign of the threat rate parameter be negative? This would mean the greater the distance at which neutrals begin to chase the fewer the number fed.

The quantitative tests used to examine factors and factor combinations were the student t-test and the Tukey test [Devore, 2000]. In order to determine the

significance of a particular term in the regression model, we used the t statistic and its corresponding p-value. The t statistic is the ratio of the parameter estimate to its standard error [Devore, 2000].

$$T = \frac{\hat{\beta}_i - \beta_i}{S_{\hat{\beta}_i}}$$, where

T is the test statistic,

$\hat{\beta}_i$ is the estimation of the true value of the coefficient on the independent variable x_i, with i = 1,…,k,

β_i is the true value of the coefficient on the independent variable x_i, with i = 1,…,k, and

$S_{\hat{\beta}_i}$ is the standard error of $\hat{\beta}_i$.

Looking for a t-ratio greater than 2 in absolute value is a common rule of thumb for judging significance because it approximates the α = 0.05 level of significance. α is the probability of rejecting a true hypothesis about our experiment [Devore, 2000].

The Tukey test uses the Studentized range distribution and depends on two parameters, a numerator degrees of freedom (df), *m,* and a denominator df, *v*. Let $Q_{\alpha,m,v}$ denote the upper-tail α critical value of the Studentized range distribution with *m* numerator df and *v* denominator df. Values of the Studentized random variable can be found in tables given in Devore, 2000. $Q_{\alpha,I,I(J-1)}$ can be used to find simultaneous confidence intervals for all pairwise

differences $E[y_i] - E[y_j]$. We can then say with probability $1-\alpha$,

$$\bar{x}_{i\cdot} - \bar{x}_{j\cdot} - Q_{\alpha,I,I(J-1)}\sqrt{MSE/J} \le E[y_i] - E[y_j] \le \bar{x}_{i\cdot} - \bar{x}_{j\cdot} + Q_{\alpha,I,I(J-1)}\sqrt{MSE/J}$$

for every *i* and *j*. Each interval which does not include zero yields the conclusion $E[y_i]$ and $E[y_j]$ differ significantly at the level α. The typical sequence of steps simplifying this procedure is as follows:

1. Select α and find $Q_{\alpha,I,I(J-1)}$ from a table such as in Devore.

2. Determine $w = Q_{\alpha,I,I(J-1)} \bullet \sqrt{MSE/J}$.

3. List the sample means in increasing order and underline those pairs differing by less than *w*. Any pair of sample means not underscored by the same line corresponds to a pair of means that are judged to be significantly different.

In JMP this procedure is automated and thus it is very easy to test over the range of a particular factor to see where, within that range, the settings group together and hence are not significantly different. An additional benefit of this test in JMP is the JMP output. JMP automatically creates what it calls the *means diamonds* plot. The plot clearly shows the spread of the number fed at each setting of the parameter. Furthermore, the means diamonds plot reveals the trend in the number fed as the parameter takes on the range of its values. When coupled with the Students t-test and the Tukey test, the plot identifies the significant difference between factor settings.

In this chapter we have laid out the methodology we followed to generate, process, and fit our data. Chapter V explains in much greater detail the process of fitting our regression models to our full dataset. We then defend these models and present summary statistics and interesting findings. We look at specific parameters of interest and several interactions. Throughout the chapter we highlight the operational insights gained from the results.

V. RESULTS AND CONCLUSIONS

As far as the laws of mathematics refer to reality, they are not certain; and as far as they are certain, they do not refer to reality.

Albert Einstein (1879 - 1955)

If scientific reasoning were limited to the logical processes of arithmetic, we should not get very far in our understanding of the physical world. One might as well attempt to grasp the game of poker entirely by the use of the mathematics of probability.

Vannevar Bush (1890 - 1974)
Pivotal figure in hypertext research

A. CHAPTER INTRODUCTION

This chapter details the iterative process we used to fit our final regression model. After examining the signs of the coefficients on the main effects and the resulting 2-way interactions, we present summary statistics and conclusions based on this model. We identify the squad/state/factor combinations found to be *important* and suggest how these combinations may be exploited during future operations. Finally, we cover follow-on regression models we explored as a result of our findings when we fit the final model.

B. FITTING THE MULTIPLE LINEAR REGRESSION MODEL

In this section we build our final linear model. The process followed to generate this regression model is explained and the underlying assumptions of the model are checked. Several main effects and interactions are tested

or examined more closely. Finally, we present the results and suggest interpretations.

1. Fitting the Main-Effects-Only Model

To begin fitting the main effects of our original 40 combinations, we started with no terms in the model and used the forward stepwise regression procedure in JMP to add terms. A factor combination was initially included in the regression model if its p-value was less than 0.25. The initial selection found 23 squad/state/factor combinations out of the original 40 met the criteria. The R^2 associated with this equation was 0.6041. Before looking more closely at the terms which survived the initial screening as described in Chapter 4, we considered the effect of striking those terms that had been factored out by our stepwise regression process.

Three groups of factors surfaced as not being important in predicting the number fed in our simulation. Based on the thousands of runs made in the months prior to designing our full experiment, we had targeted the cohesiveness of the convoy, the movement of the red agent, and the interactions between the convoy and the aggressor as three of the areas we wanted to study. Almost all of the 17 factor combinations not included in the first cut fell into one of these categories. We then set out to determine why these parameters were excluded.

Terms such as the convoy’s propensity to move toward its waypoints, alive or injured friends, or toward its enemies were included in our setup and were meant to measure cohesiveness. In our analysis these factor combinations were not significant. We found a ready

explanation. These parameters were highly dependent on the benign environment we had created. The convoy’s cohesiveness was never fully tested in our setup, in part because the momentum of the convoy and their programmed immediate action drills simply propelled them toward their final goal, feeding neutrals. Furthermore, the aggressor’s actions of shooting and running away did not have a significant effect on the pursuit of the convoy by the northern neutrals.

The same reasoning helped to explain the non-effect of the red agent’s movement and his interactions with the convoy. We thought the aggressiveness of the enemy agent (his propensity to move toward the convoy) would impact the number fed. After fitting our model we determined the movement pattern of the aggressor, while it may have been significant if we were measuring something besides the number of neutrals fed, did little to affect neutral or convoy movement.

Likewise, terms such as the number of hits to kill the convoy or its propensity to move away from red, also were not significantly tested in our setup. Rarely did the red agent ever actually kill a truck (an outcome that would have impacted the number fed) and the convoy’s response to the aggressor did not inhibit the number fed. In fact, the response may have contributed to feeding more neutrals. In the end, we were comfortable leaving these factors out of the fitted equation.

Next, we wanted to continue to whittle down the number of squad/state/factor combinations while maintaining the explanatory power of the model. Each variable with a p-

value over 0.02 was individually removed from the equation while the p-values of the remaining combinations were checked to see what effect removing the variable had on the overall R^2. This iterative process did not involve simply going from the top of the list to the bottom and removing factor combinations. Instead we began with the largest p-values and worked our way through the combinations. In some cases this meant returning parameters to the equation that had previously been removed if their p-values dipped back below 0.02 as a result of some other factor combination being removed.

By the time this process was finished, the Main-Effects Model consisted of 11 squad/state/factor combinations and had an R^2 of 0.5824. We had reduced the size of the regression model from 40 variables to 23 and then further reduced it to 11 variables. This only reduced R^2 by about 2 points. With a core set of main effects, we now had the difficult job of justifying the inclusion of these factor combinations in our model. To do this we began by considering the signs of the coefficients. We address these problems in the next section but pause first to capture the benefit of our research to this point.

There were two primary takeaways from this portion of our research. First, we encountered for ourselves the trouble one has when trying to measure logistical effectiveness in an agent-based modeling environment. We felt the variable combinations which emerged from our fitting process were closely tied to the way we had set up our simulation. The setup of our simulation was driven in part by the MOE offered by the software (number of red/blue

killed). Using a combat measure as a surrogate for measuring the number fed may have arbitrarily introduced error into our fitted model. Since we began our research, MANA has implemented functionality which allows the modeler to use the refuel parameters to measure commodity rates.

Calling attention to this limitation in PA’s suite of agent-based modeling platforms has already had an impact. This author was privileged to work with the developers of SOCRATES, an alternative agent-based modeling environment at a logistics workshop in December 2002. The need to be able to explicitly model the retention, transfer, and consumption of resources was identified to the developers during this workshop. They have quickly updated the program to include these functions. While the SOCRATES model has nothing directly to do with this research, we believe we helped to “get the ball rolling” by identifying, in the early stages of our simulation setup, the need to model logistics explicitly.

A second takeaway to this point is validation of the data farming process. When we proposed this research, we identified we were setting up a highly interactive scenario with many possible factors and interactions. What we had hoped for from the first step of our data farming process was to be able to cull the relevant factors out of the 40 original parameters and still be able to account for much of the variability in our scenario. This, in and of itself, would be a great benefit of our experiment for future decision makers given the complexity of the scenario and the number of factors we explored. So we were very pleased with these initial results. They proved the

utility of coupling agent-based simulations with smart experimental designs. This process allowed us to quickly narrow the problem space in a highly complex scenario.

2. Interpreting the Significant Squad/State/Factor Combinations

We began interpreting our Main-Effects Model simply by considering the signs of the coefficients on each of the included main effects. As an example, if we set the *movement speed* to *high*, we hypothesized fewer northern neutrals would be fed because the convoy would outrun them. An immediate way to check this theory was to ensure the sign of the coefficient on *movement speed* in our fitted model was negative. The following list summarizes the 11 main effects emerging from the stepwise regression, the signs we had expected for each of these main effects, and our reasoning behind these predictions.

- convoy_default_speed – the faster the convoy traveled the less of a chance the pursuing northern neutrals would have had of maintaining contact. Therefore, we predicted the sign would be negative.
- security_default_speed – the same reasoning as convoy speed applies.
- SN_comms delay – we expected a negative sign because the longer it took to post information to the SA map the more of a delay in acting on that information and therefore fewer should be fed.
- NN_threat rate – this parameter should have produced a positive sign because the longer it took for sightings to degrade from the SA map, the more time was allowed for neutrals to act on that information.
- NN_comms delay – we thought the opposite reasoning would apply to *comms delay*. The longer it took to post a sighting to the SA map, the less time neutrals would have had to move toward

the convoy’s location. This should have resulted in a negative sign on the coefficient.

- NN_threat size - as the ring that induces a neutral’s actions became bigger, those actions occur earlier, resulting in more neutrals being fed. We expected *threat size* to result in a positive sign.
- NN_precision – the *precision* with which the neutrals moved should have resulted in more of them being fed. Since, in MANA, a lower *precision* starting value causes more precise movement, it should also have led to a positive coefficient.
- NN_default_sensor range – we reasoned the further away the neutrals could sense the convoy, the more opportunity they would have to chase it, resulting in a positive sign.
- NN-contact_sensor range – the same argument holds for those neutrals that were in contact with the convoy. In this context, a larger range facilitated maintaining contact and a positive sign would have resulted.
- aggressor_precision – unlike the northern neutral *precision*, a less precise aggressor (a higher starting value) should have led to more neutrals being fed since the aggressor wanted to harass the convoy. The sign should have been positive.
- aggressor_default_SSKP – the aggressor’s kill probability, when higher, would have resulted in fewer neutrals being fed, hence a negative sign.

Table 3 summarizes the main effects, the sign we hypothesized we would see, and the actual sign emerging when we fit the final regression model. Areas of discrepancy are highlighted.

Squad/State/Factor	**Predicted sign**	**Actual sign**
convoy_default_speed	-	-
security_default_speed	-	-
SN_comms delay	-	-
NN_threat rate	**+**	**-**
NN_threat size	**+**	**-**
NN_comms delay	**-**	**+**
NN_precision	-	-
NN_default_sensor range	+	+
NN_contact_sensor range	+	+
aggressor_precision	**+**	**-**
aggressor_default_SSKP	-	-
aggressor_default_sensor range	-	-

Table 3. Predicted and actual signs of main effect coefficients.

The fitted model returned some counterintuitive signs on the squad/state/factor coefficients. The combinations we felt the need to further study and explain were NN_threat rate, NN_threat size, NN_comms delay, and aggressor_precision. Considerable thought was given in order to explain the difference and decide whether to continue to include the term in our final model. Here we present our conjectures as to why the signs were not what we expected.

Whenever a neutral’s state was changed to *enemy contact* that neutral would then seek out threat level 3 enemies using information posted to the SA map. The *threat rate* measures the amount of time it takes before a posting to the SA map disappears. It was not clear what the effect

of leaving sightings on the map would have. On the one hand, with many neutrals posting sightings, there begins to be a clutter of observations on the map. Furthermore, they appear in various places and last for various amounts of time. Figure 13 shows this situation. In the picture we see their have been several convoy sightings as the trucks made their way across the top of the scenario and passed the northern HA site. It may be information of this type is just not useful to neutrals trying to pinpoint the location of the convoy. On the other hand, if sightings disappear from the map almost as soon as they are posted, the information that does appear is always current, fresh information. This may be more useful to neutrals when they attempt to target the convoy. In this case, a lower threat rate starting value would result in more neutrals being fed and a negative sign on the coefficient. In the end we were convinced by this reasoning and decided to leave the parameter in the model.

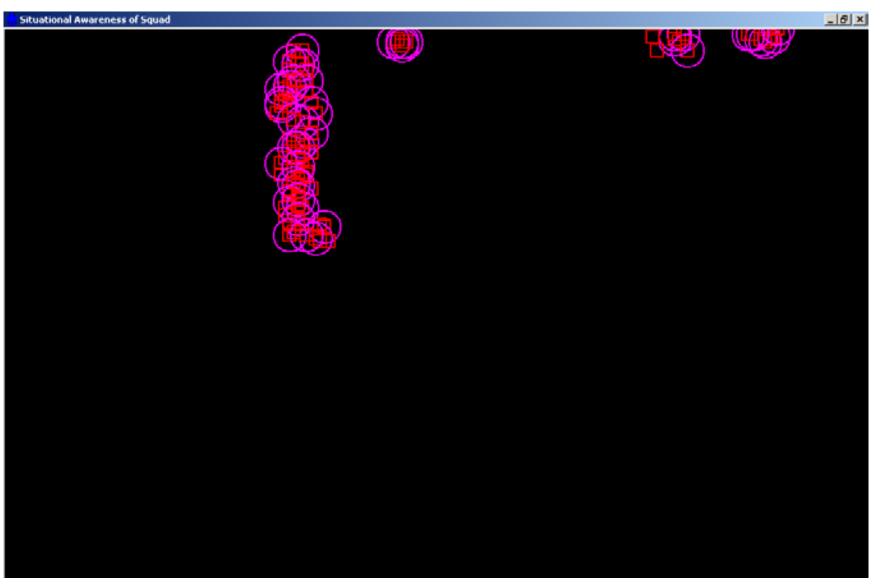

Figure 13. Northern Neutral’s SA map depicting many sightings as a result of a long threat rate.

Threat size indicates the size, in pixels, of the ring of action around an agent. The agent will react to other agents who enter this ring. Here we believed we had the possibility of intricate interactions emerging between this parameter and sensor range, line-of-sight, and relative movement speeds. We thought it was possible we may have misjudged the emerging sign of this factor. Furthermore, when we removed this main effect, the explained variation dropped by almost 10 points indicating the variable was indeed significant. Northern neutral *threat size* was retained in the regression model.

We found the coefficient for *comms delay* varied. Sometimes it was positive and sometimes it was negative depending on what model we fit. In order to explain why, we made numerous individual runs specifically to test the *comms delay* parameter. We found when we set the parameter to one (virtually no delay), sightings would post to the SA map immediately. When we set it to 500, sightings would <u>also</u> post immediately. No matter what experiment we attempted, the value of *comms delay* played no part in the way information was posted to the SA map. We have yet to verify why this is and decided not to include this factor in our model.

The simulation was set up so that if the aggressor entered the HA site he would opt to receive food rather than shoot at the convoy. We believed this was a small point but a better depiction of reality. We wanted the aggressor to act as if the convoy was more vulnerable while en route. Once it reached the HA site, the red agent was

to consider it to dangerous to act aggressively. The convoy would inevitably deploy its organic security element and possibly also have additional security at the site. It was unclear to us at this point whether aggressor *precision* would always lead to a positive coefficient. For this reason, we decided to leave this factor in the regression equation.

After striking the southern neutral and northern neutral *comms delay* from the model, our final main effects regression model had nine terms and an R^2 of 0.5304. We next wanted to include main effects and their quadratic terms.

3. Fitting the Quadratic Model

Our next step was to add the quadratic effects beginning with the Main-Effects model. JMP facilitated this simply by choosing the *fit polynomial to degree* command. We began with the nine factor combinations that had survived the previous screening process. We had determined ahead of time we would only include the squared term if the main effect was already in the regression equation. After executing forward stepwise regression in JMP, the resulting model had 14 variables with a p-value less than or equal to 0.10, the number we had set as our cutoff value for entry into the equation. The R^2 associated with this model was 0.5829, so the five quadratic terms did capture some additional variation in the number of neutrals fed. Before building the final regression model, we wanted to determine the number and type of interactions we might see so our next step involved removing the quadratic terms and fitting 2-way interactions

to see how well the model could explain the variability in number fed.

4. Fitting the 2-way-Interactions Model

Beginning with the nine factor Main-Effects model, we fit all the 2-way interactions as well. Again, a main effect must have been in the model for its interaction with another term to appear as well. Our technique at this stage was slightly different however. Rather than using forward stepwise regression to add terms, we began with all the main effects and 2-way interaction terms initially in the regression equation and then cut out those that did not contribute significantly to predicting the dependent variable.

By using this technique, we bounded our possible outcomes at either end. In other words, we started fitting the Main-Effects model with no terms and then added factor combinations. We started the 2-way interactions model with all possible terms and then removed combinations. We felt the junction of these two techniques provided bounds for the *best* regression model. The *best* equation, based on our judgment and statistical tests was somewhere between these two extremes.

We also used an iterative approach to finding this model. The regression model which immediately emerged was based on removing from the equation factor combinations with a p-value > 0.15. Then the interactive process described above was applied in order to individually remove a term, observe the effect on the remaining p-values and R^2, followed by removing another term until we had an acceptable model. The final equation included only

squad/state/factors with p-values less than 0.10 of which there were 26. The R^2 associated with this regression equation was 0.6078. We were now ready to fit a final model including main effects, quadratics, and 2-way interactions.

5. Fitting the Final Model

Our final objective was to combine all three of the previous models to find the best equation which included main effects, 2nd degree polynomials, and 2-way interactions. The process used was a backward stepwise regression. We initially allowed the nine combinations, found to be significant in the main effects screening, into the equation. Additionally, all of their squared terms and 2-way interactions were entered. We used backward step regression to screen out any variables whose p-value was greater than 0.05. The author then individually removed and tested parameters with p-values greater than 0.01. The difference between the 0.05 regression model and the 0.01 model was not much in terms of the final R^2. Prior to the individual screening R^2 was 0.6414, after screening it dropped by only 1 percentage point to 0.6310. The Final model includes 20 terms; nine main effects, three quadratic effects, and eight 2-way interactions. Having a complete equation we believed to be initially acceptable, we began checking our assumptions.

6. Checking our Assumptions

A generally accepted method of verifying the underlying assumptions of regression analysis is to view graphs output from the fitted model. We used the actual number fed vs. the predicted number fed graph and the residuals vs. the predicted number fed graphs. To get a

general idea of how well the prediction of the number fed followed the actual number fed, we began with the plot in Figure 14.

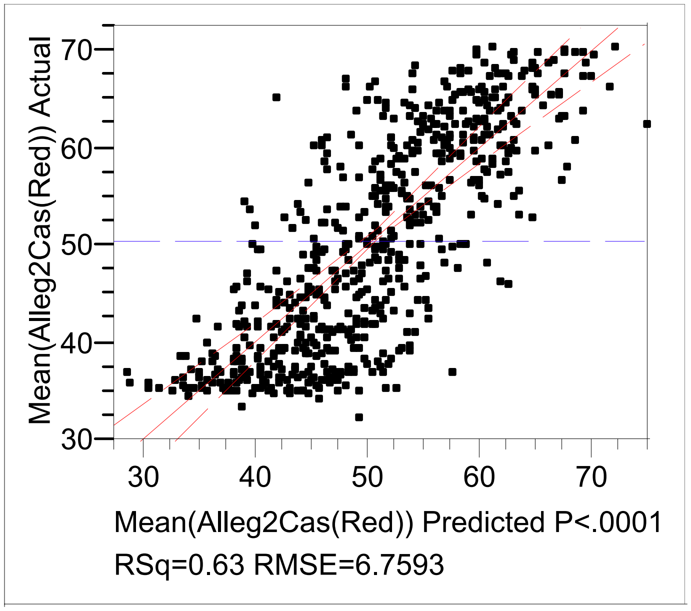

Figure 14. Actual by Predicted Plot

The actual number fed vs. the predicted number fed plot shows the general predictive capability of the model. In our case the slope is positive, indicating the prediction and actual amounts generally agree. The plot also shows the average number fed (indicated by the dashed blue horizontal line) is just over 50.

Another view of the same information is the residuals vs. predicted plot, Figure 15. We were somewhat concerned when we first saw this plot that we might have violated one of our assumptions. Namely, the residuals should be identically distributed with a mean of zero and constant variance. The following plot shows a distinct pattern we would not expect if the residuals truly identically distributed with a mean of zero.

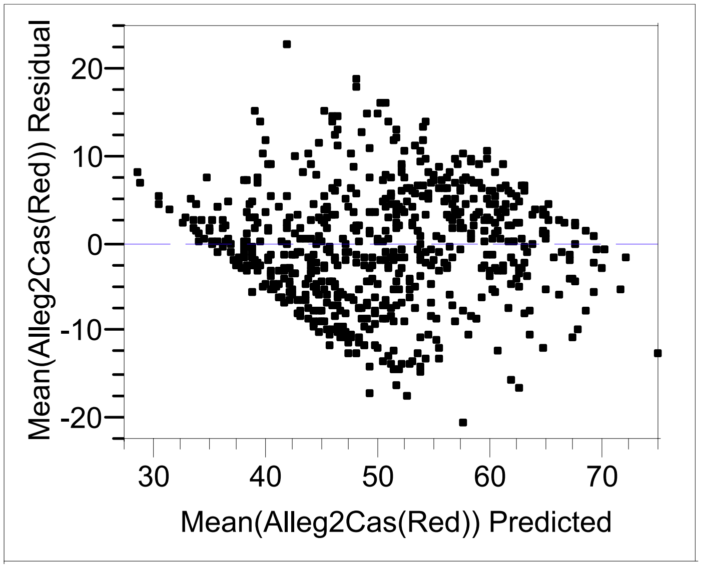

Figure 15. Residual by Predicted Plot

This shape usually indicates a trend in the data (perhaps due to an interaction) that has not been adequately modeled. After careful consideration, we believed this pattern simply captured an aspect of our model setup that only became apparent in the residual plots because of the large range of factor levels we explored. The following example is used to explain what we thought was occurring.

Because the setup of the simulation forces the southern neutrals to almost always receive food yet only encourages the northern neutrals to chase the convoy, a prediction of, say, 30 will most often be an under-prediction of five. Likewise, a prediction of 31, 32, or 33 will also often be under-predictions of four, three, two respectively. This accounts for the heavy line of points falling diagonally across the lower-left portion of the screen. At the upper-right end we see the opposite effect of this same pattern. A prediction over 70 must

necessarily be an over prediction because there are only 70 neutrals in the model. With this explanation in mind, if we turn the plot on the diagonal and then look to see if the points are evenly distributed, we see that they are.

The first plot verified for us predictions were reflective of the actual number fed. In the end the second plot confirmed consistent variance. Taken together, we were satisfied the model met the necessary assumptions of multiple linear regression. Our next objective was to look more carefully at some of the individual squad/state/factor combinations.

7. Considering Individual Squad/State/Factors

In order to get an idea of the impact individual variables had on the number fed and to identify the parameter settings having the most impact on mission success, we performed one-way analysis of variance tests. While we treated all nine significant combinations to this process, we present only the most dramatic examples of our findings here. Throughout our modeling there were several parameters which repeatedly presented themselves as being significant and about which we never had any doubt as to their interpretation in the model. We will now look more closely at these squad/state/factors. We chose to examine these variables by performing the t-test and the Tukey comparison test over the range of their settings. We wanted to determine in what range the factor combinations were significant. This information would be useful for those preparing for an HA/DR mission.

The following two figures, Figures 16 and 17, show means diamonds plots of the average number fed vs. the

northern neutral default *sensor range*. The spread of the number fed shows up vertically at each setting of the independent variable. The diamond indicates the 95% confidence region. That is, the area where we predict with 95% confidence that the true number fed lies. The blue line connects the means of each diamond. The red numbers (enclosed in the oval) and red circles indicate regions where there is no statistically significant difference between the settings.

Notice the distinct bifurcation of the range. From the beginning of our analysis we theorized the canalizing effect of the streets and buildings would play a part in the outcome of our experiment. We cannot say for certain what the optimal sensor range should be but we can say there is a difference between ranges below 20 and those above 20. These plots show sensor settings below 20 are not statistically significantly different. They group together. Factor settings of 20 or above are different from the lower numbers.

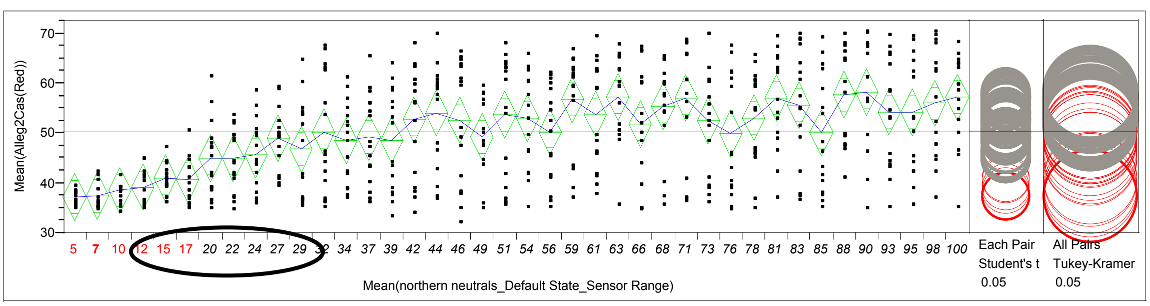

Figure 16. One-way analysis of the number fed vs. northern neutral default sensor range. Numbers in red are not significantly different from one another.

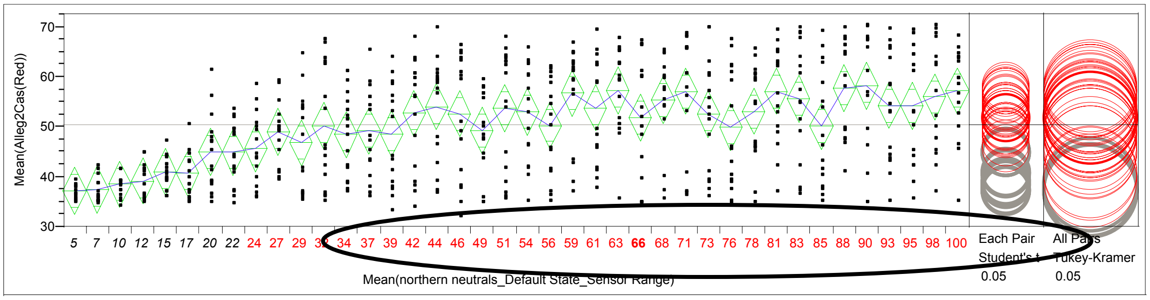

Figure 17. One-way analysis of the number fed vs. northern neutral default sensor range. Numbers in red are not significantly different from one another.

The one-way analysis plot of northern neutral *precision*, Figure 18, shows very distinctly the trend in the number fed as a result of the deliberate movements of the neutrals. This information may be useful when coupled with an understanding of the local population's penchant for purposeful action.

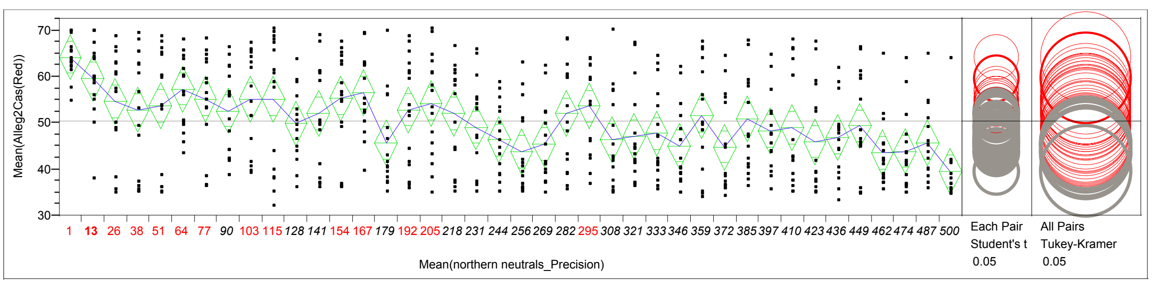

Figure 18. One-way analysis of the number fed vs. northern neutral precision. Less precise movement (higher settings) leads to fewer neutrals being fed.

Because of our uncertainty regarding the *threat rate* parameter, we were interested to see what effect this factor had individually on the number of neutrals fed. The *threat rate* plot, Figure 19, shows three groupings or a step-down effect. Originally we thought a longer rate would result in more neutrals being fed and that seems to hold true at lower values of the parameter where the number

fed is above the mean. As postings stay on the SA map for a longer time however, the number drops. Our speculation regarding the effect of having too much information, or clutter on the SA map, may be true above a certain threshold. In a dynamic urban environment, acting immediately on current information has a higher payoff than just responding to more information.

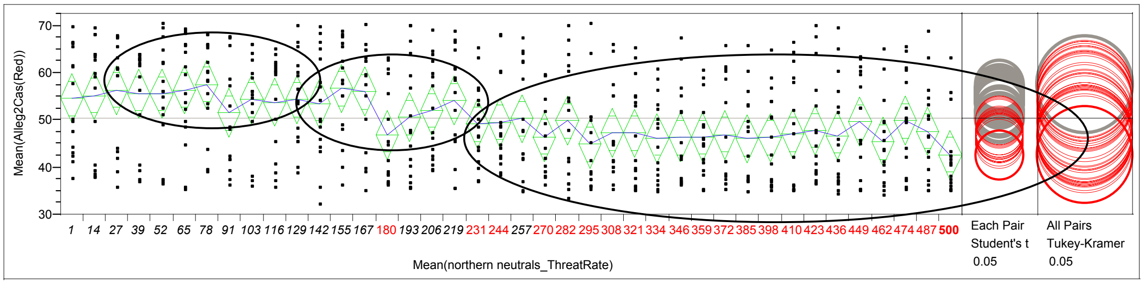

Figure 19. One-way analysis of the number fed vs. northern neutral threat rate. The longer information stays available, the fewer neutrals are fed.

Having identified interesting effects of individual factors we turned our attention to interactions between variables. Based on what we had uncovered about factors that were important and what type of effects those parameters had on mission success we expected to identify nonlinearities in the way terms interacted.

8. Considering Interactions

We wanted to determine what effects the interactions were having on the number fed so we turned to contour plots as an exploratory tool. These graphs plot two variables along the axes and depict the dependent variable as contoured regions within the body of the plot. The contours reveal how the number of neutrals fed varies as the range of the two factors varies.

The first plot, Figure 20, shows the result of crossing the northern neutral's default *sensor range* with convoy default *movement speed*. It appears when *sensor range* is below about 30 it does not matter how fast the trucks travel. In all cases, the fewest number of neutrals are fed at these settings. A sensor range of 30 translates into about two city blocks in MANA. As neutrals move around the scenario, most of the time they are either inside of buildings or moving between buildings. We suspect, in order for contact to be made with the convoy before they miss the opportunity to gain initial contact, they must detect the convoy further off. Otherwise their meeting with the convoy becomes merely chance. This explanation may be useful when planning operations in the presence of a highly mobile population.

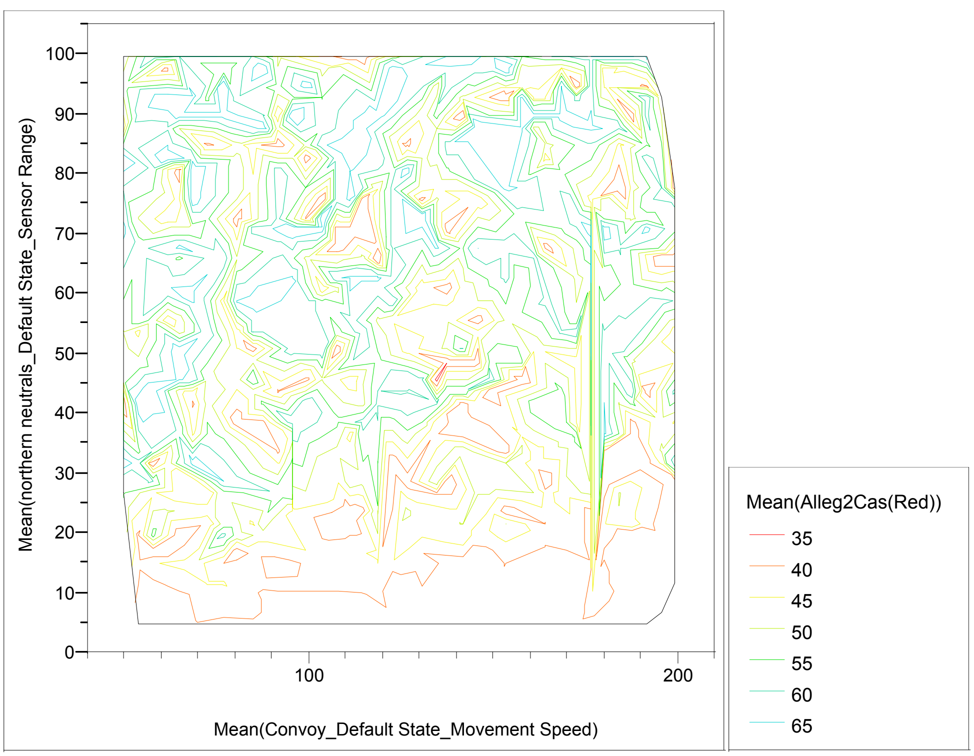

Figure 20. Contour plot of northern neutral sensor range vs. convoy movement speed. At sensor ranges below 30, convoy speed has no impact.

In Figure 21 northern neutral *threat rate* has been plotted against northern neutral default *sensor range*. The graph generally reveals regions of high payoff when *sensor range* is set at higher values and areas of lesser effect when sensors are not as capable. *Threat rate* seems to be dependent on the setting for sensor range though. Only when *threat rate* is low and *sensor range* is high do we find good results. Curiously, there is a trough (circled); an area where only 35 neutrals are fed. This is most likely where only the southern neutrals are fed. There seems to be some combination of these two factors where the northern neutrals do not tend to be as effective at chasing the convoy.

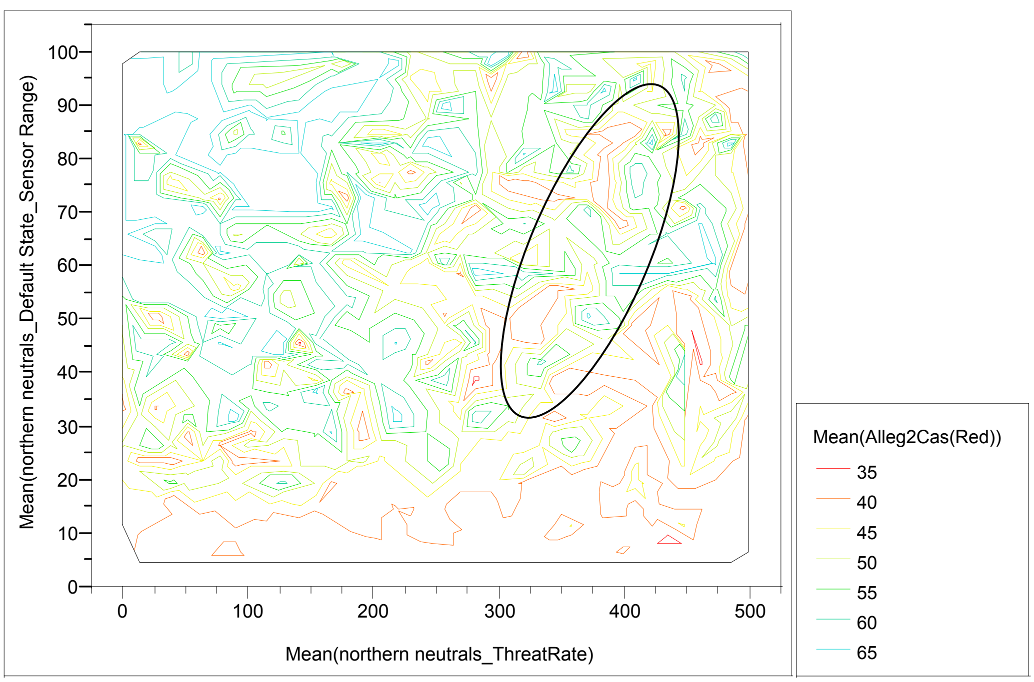

Figure 21. Contour plot of northern neutral sensor range vs. northern neutral threat rate. Notice the trough; area where only 35 are fed.

Finally, we considered the interaction of northern neutral default *sensor range* and northern neutral *precision*, Figure 22. What was interesting was the top left of the graph. It looked like there was a large area of very high *sensor range* and very precise movement where over 60 neutrals were fed. A very precise neutral would move in the most direct manner from where it was, to the northern HA site, whereas a less precise neutral may meander. Since the convoy passes immediately by the HA site, we speculated a random path would not carry the neutral to the HA site in a timely manner. That neutral may have missed the opportunity to make contact with the convoy. A more precise neutral would have covered the distance to the HA site in less time and may have been in a better position to catch the convoy as it passed.

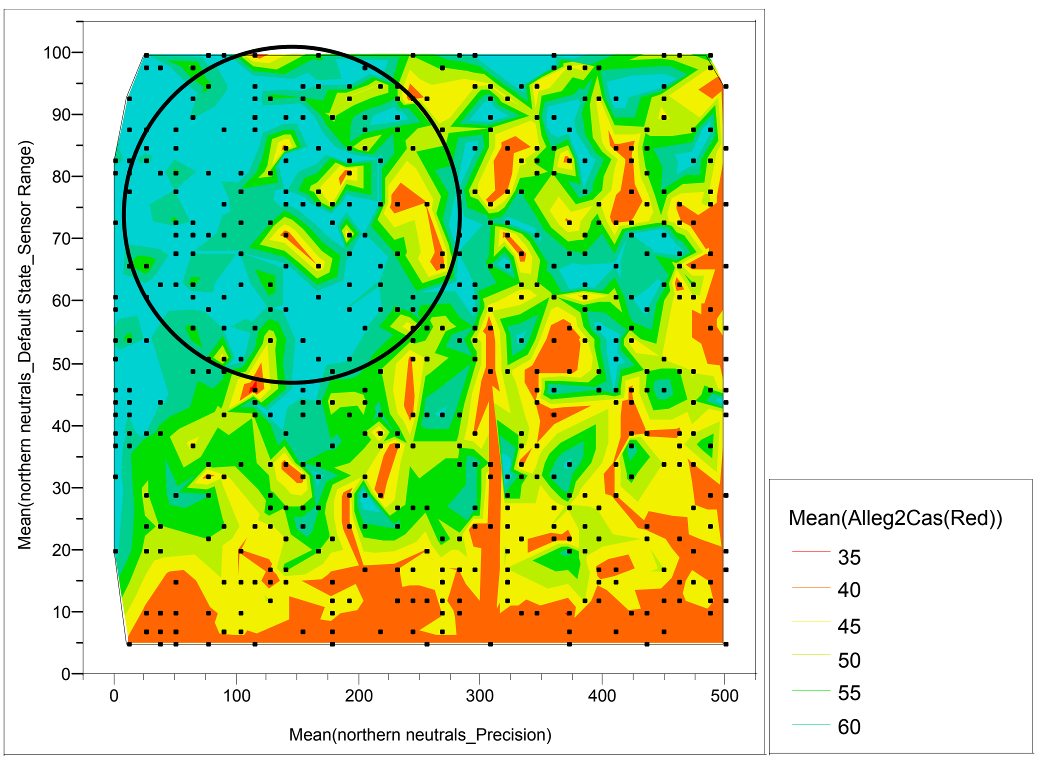

Figure 22. Contour plot of northern neutral sensor range vs. northern neutral precision. Notice the hole in the upper-left hand portion of the plot.

9. Conclusions

We close this section by summarizing a few points about our final model and then introduce the sub-models spawned by the preceding analysis. Throughout this section we have justified the squad/state/factor combinations included in our regression model. Additionally, we have interpreted the results of some of the findings. Our methodology left us with no reservations regarding the terms in our final equation. We have justified each of the main effects by qualitatively estimating their effect on the number fed. In cases where the model disagreed with our intuition, we either found a plausible explanation for the effect of the factor combination or removed the term from consideration, even if that meant having a less explanatory equation. Individual parameters were explored for their specific effect on the dependent variable. Lastly, contour plots were presented to show interesting interactions.

The summary statistics of our final regression model appear next. We stress what is important is identifying the factors and interactions themselves. We would be hesitant to suggest an equation using the coefficients.

Summary of Fit

RSquare	0.6310
RSquare Adj	0.6190
Root Mean Square Error	6.7592
Mean of Response	50.392
Observations (or Sum Wgts)	640

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	20	48361.872	2418.09	52.9262
Error	619	28280.910	45.69	Prob > F
C. Total	639	76642.783		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	62.8198	1.7451	36.00	<.0001
Convoy Default State Movement Speed	-0.0257	0.0061	-4.22	<.0001
Security Default State Movement Speed	-0.0337	0.0061	-5.54	<.0001
northern neutrals Threat Rate	-0.0179	0.0018	-9.69	<.0001
northern neutrals Threat Size	-0.0767	0.0096	-7.98	<.0001
northern neutrals Precision	-0.0248	0.0018	-13.52	<.0001
northern neutrals Default State Sensor Range	0.1815	0.0095	18.95	<.0001
northern neutrals Contact State Sensor Range	0.0743	0.0095	7.75	<.0001
Aggressor Precision)	-0.0043	0.0018	-2.38	0.0177
Aggressor Default State SSKP	-0.0353	0.0091	-3.86	0.0001
Convoy Default State Movement Speed * Security Default State Movement Speed	-0.0005	0.0001	-4.03	<.0001
Convoy Default State Movement Speed * northern neutrals Threat Size	0.0005	0.0002	2.54	0.0112
Convoy Default State Movement Speed * northern neutrals Default State Sensor Range	0.0006	0.0002	2.90	0.0038
northern neutrals Threat Rate * northern neutrals Default State Sensor Range	-0.0002	0.0000	-3.03	0.0026
northern neutrals Precision * northern neutrals Default State Sensor Range	-0.0002	0.0000	-3.78	0.0002
northern neutrals Threat Rate * northern neutrals Contact State Sensor Range	-0.0001	0.0000	-2.62	0.0091
northern neutrals Default State Sensor Range * northern neutrals Contact State Sensor Range	0.0012	0.0003	3.77	0.0002
northern neutrals Threat Size * Aggressor Precision	-0.0001	0.0000	-2.83	0.0048
Convoy Default State Movement Speed * Convoy Default State Movement Speed	0.0004	0.0001	2.60	0.0095
Security Default State Movement Speed * Security Default State Movement Speed	0.0004	0.0001	2.71	0.0069
northern neutrals Default State Sensor Range * northern neutrals Default State Sensor Range	-0.0030	0.0003	-7.95	<.0001

Table 4. Final Model including nine main effects, three quadratic terms, and eight 2-way interactions.

After thoroughly fitting and examining the final linear regression model, we attempted to subdivide our parameter space in order to analyze two specific nuances of our scenario. First, we considered a model fit around only those variables the Marines or their attachments could control. Next, we fit what we called the Comms-and-Sensors model.

C. OTHER REGRESSION MODELS

The process of fitting the final model stirred our curiosity about several of the squad/state/factor combinations. We wanted to explore what predictive power these combinations held in their own right.

1. The Marines-Only Model

We were curious to know how much control the Marines could have over the number of people fed irrespective of the actions of the neutrals resident in the environment in which the Marines operated. One way to get at this would be to try fitting a model consisting of only the factors the Marines and their attached relief agencies could prepare, control, or train for -- things such as convoy speed, unit cohesion, and hardening of the vehicles. So we fit what we called the Marines-Only model by allowing into the equation only the factor combinations affecting the convoy or the security squad.

This regression equation only explained 6% of the variability in the number of neutrals fed. We were somewhat disappointed to find the convoy was not able to judge its success based solely on the factor combinations it could control or predict. From the results, we concluded it would be very important to have some intelligence regarding the neutrals and the environment. It may be that the level of aggressiveness or cohesion of the populace plays a big role in how successful the convoy is. This makes sense but does not give the responding relief agency much flexibility to operate in an uncertain environment. Considering the importance of acquiring intelligence relating to the environment, we considered modeling the situation where the convoy broadcasts its intentions.

2. The Marines-and-Sensors Model

In this second Marines model, we considered the neutral sensor range as a surrogate for the effect of the convoy announcing ahead of time its convoy route. We hoped

by including sensor range in our Marines-Only model we could improve our prediction of the number fed and still be true to what we were trying to model. It seemed to us broadcasting the intentions of the convoy was somehow similar to exploiting the sensor range of the neutrals. The results were pleasing.

Summary of Fit

RSquare	0.3725
RSquare Adj	0.3616
Root Mean Square Error	8.7504
Mean of Response	50.3924
Observations (or Sum Wgts)	640

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	28557.047	2596.10	33.9050
Error	628	48085.735	76.57	Prob > F
C. Total	639	76642.783		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	48.5403	2.4917	19.48	<.0001
Convoy Default State Movement Speed	-0.0227	0.0078	-2.90	0.0039
Convoy Squad Shot At State SA Threat 3 (High)	0.0523	0.0235	2.23	0.0264
Security Default State Movement Speed	-0.0324	0.0078	-4.11	<.0001
northern neutrals Default State Sensor Range	0.1791	0.0123	14.49	<.0001
northern neutrals Contact State Sensor Range	0.0823	0.0123	6.67	<.0001
Convoy Default State Movement Speed * Security Default State Movement Speed	-0.0006	0.0001	-3.84	0.0001
Convoy Default State Movement Speed * northern neutrals Default State Sensor Range	0.0005	0.0002	2.02	0.0439
Convoy Default State Movement Speed * northern neutrals Contact State Sensor Range	-0.0005	0.0002	-1.94	0.0534
northern neutrals Default State Sensor Range * northern neutrals Contact State Sensor Range	0.0012	0.0004	2.97	0.0031
Security Default State Movement Speed * Security Default State Movement Speed	0.0006	0.0001	3.38	0.0008
northern neutrals Default State Sensor Range * northern neutrals Default State Sensor Range	-0.0028	0.0004	-5.86	<.0001

Table 5. Marines-and-Sensors model.

By simply including the sensor range factor the explained variability jumped to 37%. With the importance of communications on the part of the northern neutrals emerging as a greater and greater predictor in determining the outcome, we fit a final regression equation focusing on all aspects of communications.

3. The Comms-and-Sensors model

In order to fully explain the effect communications and sensors had on our scenario we focused our last regression model on fitting only these factor combinations. Throughout our analysis the efficiency of northern neutral communications continued to be highly significant. By allowing into the equation only squad/state/factors having an effect on communicating and sensing we hoped to quantify this effect.

We built this equation by initially allowing every squad's *threat rate*, *threat size*, and *sensor range* into the model. We would have preferred to include *comms delay* as well but the same uncertainty as addressed above prevented us from including this parameter. The main effects, quadratics, and 2-way interactions were fit. A p-value of 0.10 was chosen as a cut-off point for initial inclusion in the regression equation and then the author manually removed factor combinations with p-values greater than 0.01. Initially we thought the results were disappointing. The model captured only about 45% of the variation.

Summary of Fit

RSquare	0.4467
RSquare Adj	0.4406
Root Mean Square Error	8.1910
Mean of Response	50.3924
Observations (or Sum Wgts)	640

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	34239.675	4891.38	72.9039
Error	632	42403.108	67.09	Prob > F
C. Total	639	76642.783		<.0001

Parameter Estimates

Term	Estimate	Std Error	T Ratio	Prob>|t|
Intercept	48.8528	1.2987	37.62	<.0001
northern neutrals Threat Rate	-0.0211	0.0022	-9.59	<.0001
northern neutrals Threat Size	-0.0826	0.0115	-7.16	<.0001

Term	Estimate	Std Error	T Ratio	Prob>|t|
northern neutrals Default State Sensor Range	0.1849	0.0115	16.06	<.0001
northern neutrals Contact State Sensor Range	0.0717	0.0115	6.22	<.0001
northern neutrals Threat Rate * northern neutrals Default State Sensor Range	-0.0002	0.0000	-3.44	0.0006
northern neutrals Default State Sensor Range * northern neutrals Contact State Sensor Range	0.0011	0.0004	2.79	0.0054
northern neutrals Default State Sensor Range * northern neutrals Default State Sensor Range	-0.0028	0.0004	-6.30	<.0001

Table 6. Comms-and-Sensors model.

A closer look revealed some surprises however. First, we noted the Comms-and-Sensors model had only seven terms; four main effects, two interactions, and one quadratic effect. Using only seven of our original 40 squad/state/factor combinations we had explained 45% of the variation in this quite complex simulation. Considering our simulation included 70 semi-autonomous agents, each responding independently to the environment around them, we considered this a helpful result. The terms themselves bear consideration.

Notice the parameters are all properties of the northern neutrals and notice further, a decision maker really only needs to know how to exploit the three main effects; threat rate, threat size, and sensor range. This is a powerful finding. It identifies where to focus intelligence assets and dramatically simplifies planning by suggesting ahead of time what type of tactical actions should even be considered. For a commander with limited assets, he or she must decide where to concentrate those assets and one great place to start would be to exploit communications between the northern neutrals.

In the final chapter we summarize the major findings. We reiterate significant insights and suggest further ways

these ideas may be applied to operational situations. Finally, suggestions for further research are laid out.

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VI. CONCLUSIONS AND RECOMMENDATIONS

> *According to the World Disasters Report 2001, over the last ten years an average of **211 million people** (emphasis added) were affected by natural disasters each year…*

Global Humanitarian Emergencies: Trends and Projections, 2001-2002

A. CHAPTER INTRODUCTION

Throughout this research we have been guided by one overarching belief: the imperative for logisticians to research HA/DR operations. The quote above can be taken as a premonition about what awaits the world in the coming year. We believe the U.S. military **will** be sent to respond to crises around the world. We also are convinced the success of HA/DR operations is highly dependent on transportation, distribution, medical support, and the many other components of logistics. This research advances the understanding of HA/DR operations by boring into the underlying issues, developing a useful tool for exploring the problem, uncovering the important factors resulting in mission success in our logistics setup, and recommending areas of concentration for decision makers.

The remainder of this chapter synopsizes the findings and recommendations of this research. Before moving to those summaries, though, we are convinced of the following:

- Logisticians must study HA/DR operations, paying attention to lessons learned and planning considerations.
- There is great utility in using agent-based models as a means of exploring highly complex scenarios.

- Logistics functionality and measures of effectiveness must be included in agent-based models in order to fully exploit their benefits.
- Coupling intelligent designs with the speed of data farming can increase the number of factors that can be explored by at least an order of magnitude.
- Even though HA/DR operations are replete with variables, mission success may be dependent on only a handful of these variables.
- Interactions between the few, highly important factors accounts for much of mission success.
- When conducting logistics operations in an HA/DR environment, understanding and tapping into local communications is the key to mission success.
- Marines should not predict the success of a mission solely on the variables they have control over.

B. HA/DR OPERATIONS

1. Conclusions

The U.S. military faces the possibility of responding to two types of humanitarian or disaster scenarios. First, they can be sent to an area affected by a natural disaster in order to provide immediate, interim life-saving and relief support. They could also be called to a man-made disaster area, either arriving immediately at the onset or intervening at a crisis stage. In either case, our forward deployed forces are trained and equipped to rapidly respond.

The number of world-wide crises has increased since the end of the cold war. This increase is tied to the rise in local and regional civil conflict, a trend which is expected to continue. With 20 humanitarian crises currently ongoing in the world and an average of 255

natural disasters a year, we believe it is inevitable that U.S. forces will be directed to respond to a crisis in the near future.

Logisticians will provide the bulk of the relief effort to future HA/DR operations. Typically, traditional infantry objectives give way to relief functions during HA/DR operations. With the infantry providing security, logisticians will be busy producing and transporting water, distributing food, building shelters, repairing roads, and providing medical relief. The burden of responsibility for success will be on the logistics community and will depend on their planning, readiness, and execution.

Appropriate measures of effectiveness must be applied specifically to the operation at hand in order to gauge the progress of the relief effort. Choosing the correct MOE entails determining whether operational tasks or tactical efforts are being measured. With this understanding, MOEs should be formed so they measure the effect the performance of a specific mission has on relieving the overall level of suffering.

2. Recommendations

Logisticians must study HA/DR planning and execution in order to prepare themselves for the inevitability of being called up for the next disaster. They have a wide variety of resources available to aid their understanding. Between internet sites (see Appendix D for a list of informative sites), periodicals, annual reports, current books, and planning factor tables and calculators, logisticians should make good use of the lessons learned by others. Furthermore, the overwhelming volume of literature

in support of HA/DR planning has to do with logistical tasks. For example, the Sphere Project’s guide to minimum humanitarian standards [The Sphere Project, 2000] devotes 200 pages to the details logistical planning.

Logisticians must understand how to form and apply MOEs in an HA/DR environment. Again, there is no need to reinvent the wheel. There have been numerous studies undertaken to identify applicable MOEs. Additionally, it is useful to review case studies of like operations and note the MOEs used in those crises. Logisticians must learn to adapt the correct MOEs and ensure they are applying the MOEs appropriately to their operational echelon.

C. AGENT-BASED MODELS

1. Conclusions

Agent-based models easily allow the researcher to develop and test a complex scenario. By inculcating autonomous agents with simple desires and letting them individually make local decisions, an almost endless number of global outcomes are possible from a simple abstraction of a complex problem. The speed with which these simulations can be created is of course, offset by the level of abstraction and this must be considered before accepting the validity of the effort. We believe the ability to abstractly model complex human interactions is well worth what we may sacrifice in terms of the detail in the simulation.

In order to be more useful in studying HA/DR operations, agent-based models must include the capability to explicitly measure the transfer and use of resources.

It is possible to concoct “workarounds” in many of the current agent-based environments but this is a poor substitute for the ability to directly measure supply levels.

2 Recommendations

Additional research should be carried out using agents to model logistics support to HA/DR operations. Our study focused on food distribution but we can easily envision analyses being conducted on any of the following scenarios:

- A study of various temporary housing options.
- A study of the migrations of displaced persons.
- A study of the spread of communicable diseases as a result of poor conditions brought on by a disaster.
- A study of the change in health of persons affected by disaster.

In addition, our model could be easily adapted to other situations. One might analyze the effect of splitting up the convoy, adding more neutrals, or additional red agents. Alternative feeding sites could be established or the convoy could stop at numerous sites. The terrain itself could be changed simply by altering the bitmap.

In any case, we were gratified to see our research was partly responsible for instigating the addition of resource capabilities in the SOCRATES modeling environment. We encourage MANA and PYTHAGORAS to add this functionality to their products as well. We encourage analysts to begin exploring these capabilities. We envision a suite of logistics models comparable to the set of *urban* models and

weapons effects models that currently exist for some of the software packages.

D. DATA FARMING AND DESIGN OF EXPERIMENTS

1. Conclusions

Data farming, coupled with an intelligent design of experiments, gives the researcher the ability to screen for relevant factors over a very large design space. Complex problems, those including many variables and/or complex interactions, have the possibility of providing the greatest insights into HA/DR operations. In order to correctly identify the factors that are important contributors to mission success, analysts need a tool which is not limited to looking at, for example, five factors at four levels and their interactions. Our experiment considered 40 factor combinations at 640 different design points. This degree of complexity was not reasonable to explore a few years ago. To our knowledge, the highest number of factors and levels explored in an agent-based model up to this point has been 22 variables at 129 design points.

In order to explore the impact of 40 squad/state/factors simultaneously we needed to exploit supercomputing power and use an appropriate design of experiments. Our LHC design ensured we sufficiently tested each parameter over the ranges we had selected. PA was extremely helpful in farming our experiment over their supercomputing clusters. Finally, we were able to quickly generate more data when we had misgivings about the models operation at particular parameter settings. This proved to be a quick form of validation that would have been much more difficult without using supercomputing.

2. Recommendations

We recommend the data farming procedure in cases where the researcher has a complex problem and wants to explore many factors at numerous settings. We feel the supercomputing power of PA is not being exploited to its full potential. This may be because interpreting a complex model is difficult. Some researchers will opt for a simpler model that is more easily interpreted instead. We encourage the PA community to explore more factors simultaneously. They should design complex scenarios, "grow" their data in more dimensions, and use the power of the supercomputers to screen for relevant factors.

A LHC design will go a long way toward assisting in the model setup for data farming. LHC designs are intuitive, widely available, and easy to set up. There are no restrictions on the number of factors in the designs. Furthermore, it is fairly simple to check for multicollinearity between columns prior to launching one's experiment. By appending several LHC designs, as we did, the analyst can quickly and easily construct a design with little multicollinearity. This makes the interpretation of factor and interaction effects more straightforward. We recommend researchers experiment with using LHCs to set the parameter levels in their designs.

E. FITTING OUR MODEL AND MODEL RESULTS

1. Conclusions

Through fitting our various models, we uncovered five critical points. First, we found the complex environment we had modeled could be effectively described by very few squad/state/factor combinations. Secondly, those combinations having to do with local communications proved

to be vitally important. Third, interactions between these parameters provided additional explanatory power. Next, actions of the lone red agent had negligible impact. Finally, we found it was imperative for the relief agency to gather and use information from the local population. We now consider each point more closely.

It was surprising to us that we could capture so much of the variability of our scenario (63%) with only the 20 terms in our final model. When we started fitting our 40 main effects, we intended to eventually include quadratics and 2-way interactions. The possible number of terms we could have begun with was 40 main effects, 40 quadratics, and 780 2-way interactions, for a total of 860 terms. We believe we followed a rigorous screening process which stripped away those factors that truly did not have any significant explanatory power while at the same time prudently including only those which did. More importantly, we are confident we have justified the variables we kept in the model. We were able to interpret their effects in the scenario and believe we have tied their importance to decision making. Finally, the factor combinations included provided meaningful insights from which we were able to draw important conclusions.

In a system such as ours where we rely on the local population to react to our actions, we found communications between locals to be the driving factor determining mission success. After viewing our results we believe the model did not turn out to be as open-ended as we had hoped. For example, the neutrals had less autonomy then we had hoped and some of the parameters ended up either not measuring

what we had hoped or not even being relevant. Furthermore, the movement algorithms and MOEs in MANA (number of red/blue killed) drove, to a certain degree, our model setup. We would have preferred a less scripted setup. Nonetheless, the simulation we developed was a realistic scenario and in hindsight, the results agreed with our intuition. If a relief agency were to find itself operating on urban terrain where there are line-of-sight and movement speed issues, the manner in which *the word* is passed becomes a critical component of distributing food.

At this point it seems obvious that interactions between variables having to do with communications would be important to the outcome. When we began, however, the way in which these factors interacted was not obvious. For example, we reasoned both *threat rate* and *sensor range* would be important and have a positive correlation with the number fed. After all, in the case of *threat rate*, the longer a sighting remained on the SA map, the more information available to northern neutrals pursuing the convoy. Also, the farther away the northern neutrals could sense the convoy, the longer they would have to react. As it turned out though, the coefficient on *threat rate* was negative. When we then looked at the interaction between these factors, the coefficient was also negative owing to the negative *threat rate* coefficient. We would not have predicted this at the outset.

We fully expected the harassing fire of the aggressor to impact the number of people fed. Since our red agent was modeled as timid, he would almost never fire and hit enough times to destroy a vehicle. It turned out as long

as a truck was not destroyed; there was no correlation between the number fed and the harassing fire. If the convoy employs a security element and sufficiently hardens vehicles, harassing fire is more of a nuisance then a predictor of mission success.

Early on we proposed parsing our squad/state/factor combinations into two groups: those the convoy could control and all others. For a time we hoped we could fit a model that would identify a group of variables the convoy had control over. This would give them the flexibility to determine tactics that increase the chances of mission success based solely on their own actions. We wanted to put their fate in their own hands. It was informative, yet disappointing, when we were not able to fit an acceptable model. In our simulation, the convoy must exploit local communication patterns to enjoy success.

2. Recommendations

Based on our results we have two general recommendations. We reiterate our invitation for analysts to try fitting very large sample spaces. Also, when operating in an urban HA/DR environment, the response the relief agency is trying to illicit from the local population must be considered. We found even when we began by trying to measure virtually every interaction our screening technique quickly identified the heart of the problem. We recommend researchers adopt this type of procedure to study highly complex scenarios. We make a cautionary remark as well. Agent-based simulations are highly abstracted and may require creative manipulation and interpretation of the parameters and MOEs when designing the simulation. Researchers may find the simulation setup

leads to inadvertently stripping away too many factors when fitting the model. The analyst must personally check factors not included in the regression model rather than simply relying on the software.

With respect to what we have learned about HA/DR operations we found that responding agencies must identify whether their relief plan requires the local population to respond to some action they are taking. If it does, that agency needs to consider how they will communicate to the locals what inhabitants are expected to do. In our case, the northern neutrals need to recognize the convoy, understand the convoy would not stop at the northern HA site, and decide to follow the convoy to the southern site. To encourage these things to happen the convoy should broadcast its route plan and distribution scheme, and generally facilitate communications between locals.

Before making our recommendation regarding convoy composition, we caution that this applies to the scenario we developed and may not apply in a different environment. Because our aggressor was relatively timid, that is, he only fired once and then ran away; the chances of impacting the success of the mission were very low. We recommend that relieving agencies thoroughly understand the nature of the threat they face. If that threat follows our pattern, a security element and lightly sandbagged vehicles are sufficient. They need not employ assets such as armored vehicles to predict success.

Finally, we recommend relieving agencies allocate intelligence assets to the task of deciphering local communications. They must not rely solely on the

parameters they have control over. Again, we invoke the disclaimer that this holds in situations similar to our scenario.

APPENDIX A. DISASTER STATISTICS

A. PEOPLE AFFECTED BY DISASTER

The following table, Table 7, relays the number of people affected by disaster over a 25 year period from 1972 to 1996. Furthermore, the table breaks these numbers down by the type of disaster. Admittedly, the term *affected* is ambiguous. The numbers come from the Department of Public Health, Catholic University of Louvain (Belgium) [CRED, 2003], who has developed a series of databases for global disaster management. We think our model is equally applicable to any of these situations and the reader is reminded of the two urban scenarios introduced in Chapter II.

	Earth-quake	**Famine**	**Flood**	**Wind**	**Land-slide**	**Volcano**	**Fire**	**Total**
72-76	1,341,084	43,563,400	18,867,313	3,116,419	17,600	34,500	8,163	66,948,479
77-81	614,626	52,122,671	31,609,232	8,199,291	1,802	28,400	44,933	92,620,955
82-86	484,431	103,246,778	28,693,409	6,399,549	4,461	106,269	33,119	138,968,016
87-91	5,071,710	75,851,888	119,779,115	22,664,204	630,750	156,740	73,693	224,228,100
92-96	753,477	21,480,303	130,433,416	18,235,163	34,914	144,685	68,613	171,150,571

Table 7. Annual average number of people affected by type of disaster and by period (1972 to 1996). Source: CRED

B. LIST OF HUMANITARIAN DISASTERS

Table 8 is dated but relays the immenseness of the on-going humanitarian situation within the world. This

information comes from the Interdisciplinary Research Programme on the Root Causes of Human Rights Violations (PIOOM) [PIOOM, 2003], based at Leiden University in the Netherlands. Each country listed is followed by a three letter code indicating the reason for the humanitarian crisis: Low Intensity Conflict (LIC), High Intensity Conflict (HIC), Violent Political Conflict (VPC), or (-), indicating that a crisis exists even though there is no current conflict. Figures in the table represent a ranking on a scale of 1 to 5 of the degree of war, displacement, hunger, and disease prevalent in a country. The following scale is used:

- War – fatalities from violent and armed conflict, expressed in the number of people killed in political violence in 1997.

1 = < 315

2 = 316 – 999

3 = 1,000 – 3,162

4 = 3,163 – 10,000

5 = > 10,000

- Displacement – number of refugees and internally displaced people in 1997.

1 = < 99,999

2 = 100,000 – 316,199

3 = 316,200 – 999,999

4 = 1,000,000 – 3,161,999

5 > 3,162,000

- Hunger – calorie intake per capita, expressed in calorie supply as a percentage of requirements in 1997.

1 = 141 – 157

2 = 124 – 140

3 = 107 – 123

4 = 90 – 106

5 = 72 – 89

- Disease – expressed in terms of the under-five mortality rate per 1,000 live births in 1997.

1 = 5 - 68

2 = 69 – 131

3 = 132 – 194

4 = 195 – 257

5 = 258 - 320

	War	Displacement	Hunger	Disease
Afghanistan (HIC)	5	5	5	4
Burundi (HIC)	5	3	5	3
Angola (LIC)	3	4	5	5
Congo, DR of (HIC)	5	3	4	3
Rwanda (HIC)	5	2	5	3
Sudan (HIC)	4	5	5	2
Sri-Lanka (HIC)	4	4	4	1
Sierra Leone (LIC)	1	4	5	5
Turkey (HIC)	4	4	2	1
Algeria (HIC)	5	1	3	1
Iraq (HIC)	3	4	2	2
Mozambique (LIC)	1	2	5	5
Liberia (HIC)	1	4	4	4
Ethiopia (LIC)	2	1	5	4
Somalia (LIC)	1	3	5	4
India (HIC)	3	2	4	2
Myanmar (HIC)	2	3	3	3
Columbia (HIC)	3	3	4	1
Congo PR of (HIC)	3	1	4	2
Tajikistan (HIC)	3	2	2	2
Eritrea (LIC)	1	3	4	4
Zambia (VPC)	1	1	5	4
Uganda (LIC)	2	1	4	3
Cambodia (LIC)	2	1	4	3
Armenia/Azerbaijan (LIC)	1	4	2	1
Albania (HIC)	3	1	3	1
Chad (LIC)	1	1	5	3
Kenya (LIC)	1	2	5	2
Madagascar (-)	1	1	4	3

	War	Displacement	Hunger	Disease
Tanzania (-)	1	1	4	3
Peru (LIC)	1	3	5	1
Haiti (LIC)	1	1	5	2
Bosnia/Herzegovina (LIC)	1	4	2	1
Central African Rep (LIC)	2	1	5	3
Chechnya (LIC)	1	3	2	1
Viet Nam (VPC)	1	2	4	1
Georgia (LIC)	1	3	2	1
Guatemala (LIC)	1	2	4	1
DPR Korea (VPC)	1	1	3	1

Table 8. Current official and de facto humanitarian emergencies. Source: PIOOM

APPENDIX B. MANA VARIABLES AND THEIR RANGE SETTINGS

Following is a list of the parameters varied over, along with both the MANA User's Manual description [Anderson et al., 2003] and the representation within the "real world." Justification follows for the factor ranges we selected as settings to the full model.

A. THREAT PERSISTENCE

- MANA Definition - The number of time steps that must pass for a threat on the Situational Awareness (SA) map to decay.
- Real World Representation - As time passes information about enemy disposition and location becomes less and less reliable.
- Ranges and Justification - The SA map is shared knowledge common to all agents of the same allegiance so if one agent knows the location of enemies, all agents of the same allegiance have the same awareness. For this reason, threat persistence was not thought to have a significant impact on the outcome once an initial contact was made. In order to test this hypothesis this factor was screened over values 1-500 for all units.

B. THREAT INFLUENCE

- MANA Definition - This is a circle around an agent. An agent will respond to an enemy within this circle. Threat influence allows agents to hold off a response to an enemy agent, even though they know the enemy's location, until that enemy gets within a specified range.
- Real World Representation - An individual or squad may defer action until the enemy is within effective weapons range.
- Ranges and Justification - This setting has a significant effect on the way the neutrals respond to the convoy. A larger ring around the

neutrals causes them to begin “chasing” the trucks earlier. This factor was varied over many levels, 5-100 for the northern neutrals and the aggressor agent.

C. FUEL TANK

- MANA Definition - The amount of fuel the agent begins with.
- Real World Representation - This variable can be used in conjunction with the fuel rate variable to model any commodity that would be expended as time passes or actions occur.
- Ranges and Justification - The fuel tank feature was not used in this scenario. The values were fixed and inconsequential.

D. COMMS DELAY

- MANA Definition - The number of time steps that will pass before enemy detections will appear on the SA map.
- Real World Representation - There would naturally be an interlude of time before enemy detections are transmitted and posted to higher and adjacent units.
- Ranges and Justification - Because there are 70 neutrals, it was thought that a delay by one neutral in posting his sighting to the SA map would not have much impact on the outcome. There will be a continuing stream of input to the map, one right after another, as successive neutrals make sightings. Values from 0-500 were farmed for both neutral squads as a way to test this theory.

E. MOVEMENT PRECISION

- MANA Definition - The degree of random motion when choosing a move is established through movement precision. A small value makes movement more rigid, while a large value increases the randomness.
- Real World Representation - There should be a difference between units that are executing a mission that calls upon them to follow a route

plan and units that are patrolling. In the case of the first unit, one would expect their movement to be more direct from point A to point B. The second unit may wander a bit more as they move.

- Ranges and Justification - The convoy was given a small degree of randomness. This setting was fixed over all of the runs. Neutral movement precision was varied from 0-500; where 0 represents no randomness and 500 indicates that ½ of their movements will be in a random direction while ½ will be toward their objective.

F. FIREPOWER

- MANA Definition – This is the probability of killing an enemy with a single shot, the Single Shot Kill Probability (SSKP).
- Real World Representation - SSKP represents the accuracy of the weapon and the proficiency of the shooter.
- Ranges and Justification - The convoy will respond to any shot whether it is well aimed or not so we were interested to know how the model would react, even to shots that had no probability of a kill. We varied red's SSKP from 0 to 100. Blue's SSKP was fixed at 20 for return fire and at 100 for purposes of feeding.

G. THREAT

- MANA Definition - Threat is used as a means of differentiating between different types of threats. The value is the threat level that will appear on the SA map of an opposing unit. Threat level 1 corresponds to a low threat, level 2 a medium threat, and level 3 is a high threat.
- Real World Representation - It is the case that neutrals appear less threatening than armed enemy combatants or tanks.
- Ranges and Justification - The choice of a threat level is really arbitrary. The response to a given threat level is determined by the weight given to the variable controlling movement toward or away from that threat level. The convoy was

posted to the neutral's SA map as a high threat (3). Initially all neutrals were seen by the convoy as a low threat. Once the convoy is fired upon they see the red agent as a high threat and respond accordingly.

H. STEALTH

- MANA Definition - Stealth represents how difficult it is to see an entity once it is within an enemy's sensor range.
- Real World Representation - An enemy will use camouflage, cover, and concealment to hide his movements.
- Ranges and Justification - The stealth parameter was not varied in the set of runs. However, the red agent was set to favor stealth in his retreat path after he had taken a shot.

I. FUEL RATE

- MANA Definition - This is the amount of fuel that is consumed per time step.
- Real World Representation - The fuel rate could be used to model any resource that is consumed as time passes.
- Ranges and Justification - Because of the short duration of the mission and the fact that the scenario is bounded by run length; the fuel rate variable was not used.

J. ALIVE FRIENDS

- MANA Definition - These are weightings agents use to determine their next move, that is, a propensity to move toward or away from alive friends. A higher weighting provides a greater attraction, whereas a lower number acts to repulse the agent from alive friends.
- Real World Representation - This variable represents the cohesion a unit displays and can be used to force dispersion at one extreme and mobbing at the other extreme.
- Ranges and Justification - Initial runs proved that this variable effected the movement of the

convoy and the clustering of neutrals. In order to test the integrity of the convoy and the individuality of the neutrals we chose to vary the attraction of blue from 50-100 and that of neutrals from 0-50.

K. ALIVE ENEMIES

- MANA Definition - Similar to the alive friends variable, this is the propensity to move toward or away from alive enemies.
- Real World Representation - Depending on a unit’s mission, they may choose to close with an enemy or bypass an enemy.
- Ranges and Justification - The convoy is directed to increase its speed and move away from an enemy threat. This is accomplished by varying their levels between -100 and -50. The same weighting is applied to the red agent in his retreat state. Conversely, red is attracted to the convoy with weightings between 50 and 100 in his default state. The neutrals “chase” the convoy by varying their weights from 50-100 once they have made contact with the convoy.

L. INJURED FRIENDS

- MANA Definition - The injured friends variable captures the propensity to move toward or away from injured friends.
- Real World Representation - Each firefight is situationally dependent but it may be that a unit’s training for a given situation teaches them to rally around a downed comrade. On the other hand, the same unit may be trained to quickly move out of a kill zone.
- Ranges and Justification - Given that the convoy is directed to move away from an enemy agent, we were interested to see the results of runs made while they had competing orders to either rally around an injured squad member or away from an injured ally. We varied the settings from -25 to 25.

M. DISTANT FRIENDS

- MANA Definition - This variable controls the attraction/repulsion to friends that are far off.
- Real World Representation - This may represent a way to reestablish contact with members of the squad that become separated.
- Ranges and Justification - The distant friends parameter was not used in our scenario.

N. NEXT WAYPOINT

- MANA Definition - The propensity to move toward or away from the next waypoint is established by the next waypoint variable.
- Real World Representation - A patrol or convoy will almost always follow a predetermined route with checkpoints along the way.
- Ranges and Justification - Initial runs determined that the convoy needed to have a strong weight in order to keep them from becoming "lost," therefore convoy weights were permuted between 80-100. The neutrals are given waypoints within the HA/DA sites, that is, they were attracted to the sites. Their values were varied from 60-80.

O. ALTERNATE WAYPOINT

- MANA Definition - An alternate waypoint can be triggered by a state change. When this occurs, the alternate waypoint variable controls the attraction toward or away from that waypoint.
- Real World Representation - This could be used to model an on-order mission.
- Ranges and Justification - There were no alternate waypoints established in the model.

P. EASY TERRAIN

- MANA Definition - An agent will seek to move toward or away from easy terrain when this variable is weighted.

- Real World Representation - Convoys will want to stay on roads, whereas persons are not restricted to the roads.
- Ranges and Justification - The trucks were given a desire to stay on the roads. After the red agent had taken a shot, his desire for easy terrain went up as he retreated.

Q. SA THREAT 1 (LOW), 2 (MED), 3 (HIGH)

- MANA Definition - This variable controls the propensity of an agent to be attracted to or repulsed by a threat of level 1, 2, or 3 that appears on their SA map.
- Real World Representation - Not every enemy threat is of equal importance or concern. A tank may be seen as a greater threat than an infantryman.
- Ranges and Justification - This variable is used to induce the northern neutrals to chase the convoy by setting their propensity from 50 to 100. Prior to contact, the aggressor agent will move toward the convoy (threat level 3) with parameter settings varying between 50 and 100. After contact is made between the red agent and the convoy, blue and red both want to move away from one another by setting values of threat level 3 from -100 to -50.

R. ALIVE NEUTRALS

- MANA Definition - Similar to the alive friends or enemies variable, this is the propensity to move toward or away from alive neutrals.
- Real World Representation - A unit may be given a mission that requires it to interact with the indigenous population.
- Ranges and Justification - This variable did not come into play due to the fact that none of the agents were classified as neutrals.

S. COVER

- MANA Definition - The propensity of an agent to seek cover when moving is controlled by this parameter.

- Real World Representation - Patrol routes are usually planned in a way that maximizes use of natural cover.
- Ranges and Justification - Red was given a slight desire to seek cover as he retreated.

T. CONCEALMENT

- MANA Definition - Similar to cover, this is the propensity to seek concealment when moving.
- Real World Representation - The same explanation as is given for cover.
- Ranges and Justification - As with cover, red was given a slight inclination toward concealment when retreating.

U. SENSOR RANGE

- MANA Definition - Although MANA has the option of either a cookie-cutter sensor or a user-defined sensor, we used the default cookie-cutter sensor. The sensor range is the number of cells away that an agent can see with 100% probability.
- Real World Representation - Sensor range could be used to model any type of visual sensor.
- Ranges and Justification - All agents were considered to be using their eyes as sensors. Since agents can not see through walls, values for the northern neutrals and the aggressor agent were permuted in the range 5-100 as a means of testing what affect the urban terrain had on the use of sensors.

V. FIRING RANGE

- MANA Definition - An agent can shoot at another agent this many cells away.
- Real World Representation - Every weapon has a maximum range.
- Ranges and Justification - Due to the confining nature of urban terrain, we did not think that the maximum range of either direct fire or indirect fire weapons would be exceeded. The levels were fixed throughout all runs.

W. MAXIMUM TARGETS PER TIME STEP

- MANA Definition - This is the number of targets that are within both sensor and firing range that can be engaged in a single time step. MANA then divides this number by 100 allowing for less than one target per step or a fractional number of targets per step. So a fraction such as 1.5 is interpreted as engaging one target per time step 100% of the time and an additional target 50% of the time.

- Real World Representation - Numbers greater than 100 resemble weapons such as automatic weapons. Values less than 100 may be used to represent a bolt-action type of weapon.

- Ranges and Justification - The red agent was allowed to engage between 1 and 3 targets per time step. When the convoy reaches the HA/DR site its weapons become the means by which it delivers food. Varying the levels between 80 and 120 was seen a way to test the proficiency with which they delivered food.

X. MOVEMENT SPEED

- MANA Definition - This is the number of grids an agent can move in one time step. MANA then divides this number by 100 applying the same logic as given for the maximum targets per time step parameter.

- Real World Representation - The real world application is direct. It is worth noting however, that this movement algorithm induces hesitation and "jumps" in the way agents move which seems closer to reality than simply having constant movement rates.

- Ranges and Justification - Based on operational experience, it was felt that the speed of the convoy should be 3 to 4 times the speed of the neutrals except for in certain, unique situations. Convoy speeds varied from 50 to 200, while neutral speeds were constant except when chasing or retreating. In these cases, they doubled their speed from 25 to 50.

Y. NUMBER OF HITS TO KILL

- MANA Definition - The number of hits an agent can sustain before it is killed.
- Real World Representation - This variable is a way of modeling armor or “life force.”
- Ranges and Justification - All neutrals could be killed with a single shot. The number of hits to kill a truck within the convoy was changed 1-3.

Z. MINIMUM DISTANCE TO FRIENDS

- MANA Definition - This parameter limits the distance to which friends will approach one another.
- Real World Representation - Military units will try to keep dispersion as a means of passive security.
- Ranges and Justification - In order to test the effect of various following distances, the convoy was subjected to permutations within the range 3-15.

AA. MINIMUM DISTANCE TO ENEMIES

- MANA Definition - This parameter limits the distance to which a unit will approach an enemy unit.
- Real World Representation – The MANA factor mimics standoff range.
- Ranges and Justification - Minimum distance to enemies was not used in the experiment.

AB. MINIMUM DISTANCE TO NEUTRALS

- MANA Definition – This parameter is the same as the previous two only with respect to neutrals.
- Real World Representation – It may be that a unit wants to keep away from the local population.
- Ranges and Justification – Because the neutral and red agents were given the same allegiance, they were classified as enemies for modeling purposes and this parameter was not used.

AC. MINIMUM DISTANCE TO NEXT WAYPOINT

- MANA Definition - The variable ensures that an agent does not go closer to the next waypoint than a specified distance.
- Real World Representation - A unit may want to keep its distance from a point.
- Ranges and Justification - This variable was not invoked in this model.

AD. CLUSTER CONSTRAINT

- MANA Definition – Cluster constraint prevents the buildup of clusters of friendly entities above a specified size.
- Real World Representation – In order to provide an extra measure of security, we may want to keeps our forces dispersed.
- Ranges and Justification – We did not use the cluster constraints in our model. Although we would want to maintain separation between vehicles in a convoy, we thought that this would be hard to do in a stop-and-go, urban environment. We thought the neutrals would tend to cluster.

AE. COMBAT CONSTRAINT

- MANA Definition – This parameter prevents a squad from advancing on an enemy without a numerical advantage.
- Real World Representation – We normally want to attack with a three to one advantage.
- Ranges and Justification – Since our scenario modeled chance meetings between the convoy and the red agent we did not invoke this factor setting.

AF. ADVANCE CONSTRAINT

- MANA Definition – Similar to the other two constraints, this setting indicates the number of friendly agents that must be grouped together before the squad will advance toward its next waypoint.

- Real World Representation – If a combat team gets ambushed they may want to abort their mission unless they are at least a certain percentage effective.
- Ranges and Justification – We considered using this setting to nullify a mission if a member of the convoy became separated but by doing that we would have introduced other complications to modeling that were not easily overcome.

AG. REFUEL TRIGGER RANGE

- MANA Definition – This is the maximum distance an entity can be from the squad to be able to be refueled by that squad.
- Real World Representation – In order to pass any commodity, the parties would need to be in contact.
- Ranges and Justification – We did not pass any resources between agents so this parameter was not used.

AH. PROBABILITY OF REFUEL ENEMY/FRIEND/NEUTRAL

- MANA Definition – The probability that an enemy/friend/neutral within the refuel trigger range will be refueled.
- Real World Representation – This parameter can be used to model the instance where someone is passing out literature to people who don’t necessarily want it.
- Ranges and Justification – Again we did not pass any resources.

AI. SHOT RADIUS

- MANA Definition – This is the kill radius for the standard personal weapon. All entities within the radius have the same SSKP.
- Real World Representation – Shot radius can be used to model direct fire or area fire weapons effect radius.
- Ranges and Justification – We varied the aggressor’s shot radius between 1 and 30 to

indicate either a direct fire weapon or an area fire weapon such as a rocket propelled grenade.

AJ. ARMOR THICKNESS

- MANA Definition – The thickness (in mm) of armor as it relates to additional user defined weapons.
- Real World Representation – Represents the thickness of either body armor or vehicle skin.
- Ranges and Justification – Since we did not introduce any additional weapons into the model, we did not use this parameter. We did try to get at this construct through the number of hits to kill variable.

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APPENDIX C. JAVA CODE USED IN THIS THESIS

A. FACTOR.JAVA CLASS

The Factor class is a utility class that stores and retrieves factor information. This class creates instances of Factor with a low and high level.

```
/*
 * Factor.java
 * Created on July 22, 2003, 2:25 PM
 */

package mcwl.doe;

/**
 * Utility object to store and retrieve factor information.
 * @author  paul & susan sanchez
 */
public class Factor {
    private String name;
    private double lowLevel;
    private double highLevel;
    private int numberOfLevels;

    /** Creates a new instance of Factor.  Low level must be less
than high level.  Otherwise, high level is set to low level + 1.
     * @param n name of factor.
     * @param l low level of factor.
     * @param h high level of factor.
     */
    public Factor(String n, double l, double h) {
        name = n;
        if (l < h) {
            lowLevel = l;
            highLevel = h;
        }
        else {
            lowLevel = l;
            highLevel = l + 1;
        }
    }

    /**
     *  Creates  new  instance  of  Factor  with  low  level  set  to
negative infinity and high level set to positive infinity.
     * @param n name of factor.
     */
    public Factor(String n) {
        this            (n,            Double.NEGATIVE_INFINITY,
Double.POSITIVE_INFINITY);
    }
```

```
        /*
        public void setName(String n) {
            name = n;
        }
        */

        /**
         * Retrieve the factor's name.
         * @return the factor's name.
         */
        public String getName() {
            return name;
        }

        /**
         * Set the low level for the factor.
         * If the specified value is greater than or equal to the
high level, the request is ignored.
         * @param x desired low level.
         */
        public void setLowLevel(double x) {
            if ( x < highLevel) {
                lowLevel = x;
            }
        }

        /**
         * Retrieve the low level for the factor.
         * @return the low level for the factor.
         */
        public double getLowLevel() {
            return lowLevel;
        }

        /**
         * Set the high level for the factor.  If the specified value
is less than or equal to the low level, the request is ignored.
         * @param x desired high level.
         */
        public void setHighLevel(double x) {
            if ( x > lowLevel) {
                highLevel = x;
            }
        }

        /**
         * Retrieve the high level for the factor.
         * @return the high level for the factor.
         */
        public double getHighLevel() {
            return highLevel;
        }

        /*
        public void setNumberOfLevels(int n) {
            if ( n > 1) {
```

```
                numberOfLevels = n;
            }
        }

        public int getNumberOfLevels() {
            return numberOfLevels;
        }
        */
    }
```

B. READFACTORS.JAVA CLASS

This class reads in the factors and the range of each factor. ReadFactors then calls the LatinHyperCube class to actually churn out the design.

```
    /*
     * ReadFactors.java
     * Created on July 22, 2003, 4:08 PM
     */
    package mcwl.doe;
    import java.io.*;

    /**
     * This class reads a set of factors with low and high integer
levels from stdin.  The input must be in the form one value per line.
Its output is a number of independent Latin hypercubes with integer
factor levels spaced (nearly) symmetrically between the low and high
levels.
     * @author  paul sanchez & susan sanchez
     */
    public class ReadFactors {

        /**
         * @param args optional argument specifies the number of
replications.  Default is one replication if no command line argument
is given.
         */
        public static void main(String[] args) {
            String name;
            double l;
            double h;
            LatinHypercube lh = new LatinHypercube();

            BufferedReader     d     =     new     BufferedReader(new
InputStreamReader(System.in));
            try {
                for (;;) {
                    name = d.readLine();
                    l = Double.parseDouble( d.readLine() );
                    h = Double.parseDouble( d.readLine() );
                    lh.addFactor(name, l, h);
                }
```

```
        }
        catch (Exception e) {
        }

        int nreps = 1;
        if (args.length > 0) {
            nreps = Integer.parseInt(args[0]);
        }
        for (int n = 0; n < nreps; ++n) {
            int[][] levels = lh.generateIntegerLHDesign();
            if (n == 0) {
                for (int j = 0; j < levels[0].length; ++j) {
                    System.out.print(lh.getFactorName(j)+"\t");
                }
                System.out.println();
            }
            for (int i = 0; i < levels.length; ++i) {
                for (int j = 0; j < levels[i].length; ++j) {
                    System.out.print(levels[i][j]+"\t");
                }
                System.out.println();
            }
        }

    }

}
```

C. LATINHYPERCUBE.JAVA CLASS

The LatinHypercube class fills out the LHC by generating the factor levels derived from the Factor class, and then shuffling those generated levels.

```
/*
 * LatinHypercube.java
 * Created on July 22, 2003, 2:51 PM
 */

package mcwl.doe;
import java.util.Vector;
import java.util.Random;

/**
 *  Provides  the  ability  to  generate  square  Latin  hypercube
designs.
 * @author  paul & susan sanchez
 */
public class LatinHypercube {
    private Vector factorSet;
    private Random r;

    /** Creates a new instance of LatinHypercube */
```

```
          public LatinHypercube() {
              factorSet = new Vector();
              r = new Random();
          }

          /**
           * Adds another factor to the set of those to be studied.
           */
          public void addFactor(String n, double l, double h) {
              factorSet.add(new Factor(n, l, h));
          }

          /**
           *  Generate  a  design  with  integer-valued  factor  levels.
First generates the levels based on the user-specified ranges and the
number of factors in the set to be studied.  The design is created by
shuffling the generated levels, one factor at a time, into a random
order.
           * @param none
           * @return a two-dimensional array of integers containing the
           *    design.  Rows correspond to runs, columns to factors.
           */
          public int [][] generateIntegerLHDesign() {
              int n = factorSet.size();
              int [][] design = new int[n][n];
              for (int j = 0; j < n; ++j) {
                  Factor f = (Factor) factorSet.elementAt(j);
                  int numberIntegerLevels = (int) (1 + f.getHighLevel()
- f.getLowLevel());
                  for (int i = 0; i < n; ++i) {
                      design[i][j] = (int) (Math.rint(f.getLowLevel() +
i * ( numberIntegerLevels - 1.0)/( n - 1)) );
                  }
              }
              shuffle(design);
              return design;
          }

          /**
           * Get the factor name for the specified factor.
           * @param f the index of the desired factor.
           * @return the name of the specified factor.
           */
          public String getFactorName(int f) {
              return ((Factor) factorSet.elementAt(f)).getName();
          }

          /*
           * Private method to shuffle the raw levels, one factor at a
time.
           */
          private void shuffle(int[][] design) {
              for (int j = 0; j < design.length; ++j) {
                  for (int i = 0; i < design[j].length; ++i) {
                      int swapIndex = r.nextInt(design[j].length);
                      int tmp = design[i][j];
```

```
                design[i][j] = design[swapIndex][j];
                design[swapIndex][j] = tmp;
            }
        }
    }

    /**
     * Illustrates how to create, add factors, and generate from
a LatinHypercube object.  For testing purposes only.
     * @param args ignored
     */
    public static void main(String[] args) {
        LatinHypercube lh = new LatinHypercube();
        lh.addFactor("Factor1", 10, 12);
        lh.addFactor("Factor2", 10, 11);
        lh.addFactor("Factor3", 1, 17);
        lh.addFactor("Factor4", 10, 50);
        lh.addFactor("Factor5", 1, 5);

        int[][] levels = lh.generateIntegerLHDesign();

        for (int j = 0; j < levels[0].length; ++j) {
            System.out.print(lh.getFactorName(j)+"\t");
        }
        System.out.println();

        for (int i = 0; i < levels.length; ++i) {
            for (int j = 0; j < levels[i].length; ++j) {
                System.out.print(levels[i][j]+"\t");
            }
            System.out.println();
        }
    }
}
```

APPENDIX D. HA/DR WEBSITES

The following table is a short list of several of the key agencies involved in humanitarian assistance and disaster relief operations. This list is not meant to be exhaustive. Most of the websites listed have links to other organizations, which may specialize in specific nuances of HA/DR operations. Many agencies have posted tools such as weather updates, online journals or tables, supply calculation and tracking systems, financial tracking system, and training seminars on their websites as well.

Center of Excellence in Disaster Management and Humanitarian Assistance	www.coe-dmha.org
Relief Web	www.reliefweb.int
U.S. AID	www.usaid.gov
Center for Disaster Management and Humanitarian Assistance	www.cdmha.org
Oxfam America	www.oxfamamerica.org
World Vision	www.worldvision.org
Pan American Health Organization	www.paho.org
World Health Organization	www.who.int/disasters
Disaster Relief	www.disasterrelief.org
International Committee of the Red Cross	www.icrc.org
CARE	www.care.org
Doctors Without Borders	www.msf.org
UNICEF	www.unicef.org
Federal Emergency Management Agency	www.fema.gov
U.S. Department of State	www.state.gov
Christian Children's Fund	www.ccfusa.org

Table 9. List of informative humanitarian assistance and disaster relief websites.

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INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California

3. Marine Corps Representative
   Naval Postgraduate School
   Monterey, California

4. Director, Training and Education, MCCDC, Code C46
   Quantico, Virginia

5. Director, Marine Corps Research Center, MCCDC, Code C40RC
   Quantico, Virginia

6. Marine Corps Tactical Systems Support Activity (Attn: Operations Officer)
   Camp Pendleton, California

7. Director, Studies and Analysis Division, MCCDC, Code C45
   Quantico, Virginia

8. Professor Susan M. Sanchez
   Department of Operations Research
   Naval Postgraduate School
   Monterey, California

9. Dr. Niki Goerger
   TRADOC Analysis Center-Monterey
   Monterey, California

10. Maj Lloyd Brown
    TRADOC Analysis Center-Monterey
    Monterey, California

11. Professor David Schrady
    Department of Operations Research
    Naval Postgraduate School
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12. Dr. Gary E. Horne
    Marine Corps Warfighting Lab
    Quantico, Virginia

13. Capt Eric Wolf
    Naval Postgraduate School
    Monterey, California